STATE-WIDE COMMUNICATIONS STRATEGIC PLAN

FINAL REPORT

An added task of the

SEATTLE TO PORTLAND INTER-CITY ITS CORRIDOR STUDY

AND COMMUNICATIONS PLAN

Prepared for the
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SECTION 1 - INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

This document is the sixth and final in a series of technical memorandums provided as part of the Seattle to Portland Inter-City ITS Corridor Study and Communications Plan. The study work consists of conducting an Intelligent Transportation System (ITS) corridor study and developing a communications plan for the inter-city corridor from Portland to Seattle. There are two primary purposes for this project. The first is to develop a recommended plan for implementing appropriate ITS technologies to address corridor transportation needs over the next twenty years to provide safer roadways, better informed travelers, improved traffic management, and increased efficiency of commercial goods movements through the application of advanced technology to the State's transportation system. The second purpose is to develop a communications plan that supports the ITS corridor plan, accounts for WSDOT communication requirements in the corridor, and provides a framework for a statewide WSDOT communications network.

This memorandum provides general recommendations for a statewide WSDOT communication network. The recommendations are intended to provide an objective blue print for the 20-year communications master plan. It includes current WSDOT network systems as well as applicable future WSDOT plans and goals. It also addresses events that may impact WSDOT's communications requirements for the introduction of new communications and traffic control automation technologies along with other ITS technologies that may impact the communications network. Additionally, it considers the provision of a communications infrastructure for the support of the communication requirements of WSDOT's intra-departmental communications plus adding other state agency communications as may be appropriate. The communications plan summarizes the findings of both the corridor and statewide analysis and provides the recommended strategies for a communications network supporting WSDOT ITS and business requirements.

It is important to note that the telecommunications industry is in a state of flux due to the Telecommunications Act of 1996. This federal legislation has abolished the monopoly enjoyed by local telephone companies and will radically alter the traditional provision of telecommunications services. It is also important to note that the Act has somewhat diluted the authority of states insofar as control of their highway rights of way may be concerned with respect to occupancy by telecommunications companies. Therefore, the assumptions which support the acquisition of a state owned network may change as well as being impacted by the steady evolution of a national information infrastructure and the development of a recommended ITS architecture by the FHWA.

1.2 STUDY AREA

This memorandum addresses the major state highway corridors throughout the state of Washington. The inter-city corridor along I-5 from Seattle to Portland has been considered in depth by previous memorandums. Summary information regarding proposed communication systems along this corridor will be included for completeness.

Other corridors of interest in the state will be identified and discussed. These corridors represent the major state routes for commercial trucking, tourism and recreational travel, and inter-city passenger travel between the major cities. The long term requirements for ITS and administrative communications will be identified and a plan for meeting those needs will be presented.

1.3 ORGANIZATION OF THE TECHNICAL MEMORANDUM

Following this introduction, the technical memorandum is divided into the following sections:

Section 2 - Existing Statewide Communication Systems

Technical information on existing WSDOT communication network systems, Washington State Patrol communications network as well as the State of Washington Department of Information Services communication network.

Section 3 - Communication Technologies

A brief discussion of the available communication technologies and protocols. This section will discuss the structure of the various communication protocols. The strengths and weaknesses of several identified communication technologies will be identified.

Section 4 - Federal Legislation and Regulatory Issues

The impacts of this federal legislation on the WSDOT communication network will be discussed. Other regulatory issues that may influence the development of the statewide system will be identified and their potential impact discussed.

Section 5 - Statewide Communication System Needs

Identification of needs on a statewide basis for ITS, traffic control, and WSDOT's Intra-Departmental Needs. This section will also discuss the impact of new communication and ITS technologies, inter-departmental needs and any future events that may impact communication needs and capabilities.

Section 6 - Strategies for the State-wide System

Various communication strategies will be discussed and evaluated. Financial considerations for development of a statewide system will be identified and considered. Recommendations on the strategies for implementation will be given.

Section 7 - Recommended Corridor Communication Strategies

The recommended corridor communication strategies for a statewide communication network will be discussed.

Section 8 - Prioritized State Corridors for Further Study

Selected State corridors will be discussed and prioritized for further study.

Section 9 - Summary of Recommendations

A summary of the recommendations of this technical memorandum for a statewide communications network supporting WSDOT ITS and business requirements will be presented.

Glossary of Terms

Provides a brief description of technical terminology used in the report.

Appendix

Provides a technical description of various communication technologies referred to in this report.

SECTION 2 - EXISTING STATE-WIDE COMMUNICATION SYSTEMS

This section will provide an overview of existing communication systems that are state-owned either by WSDOT, WSP or other state departments.

2.1 WSDOT OWNED SYSTEMS

2.1.1 Northwest Region SC&DI

The Northwest region is currently installing a digital broadband communication system utilizing a synchronous optical network (SONET) transmission architecture in parallel with an analog video transmission system. The state-owned system has begun to support a planned Surveillance, Control, and Driver Information (SC&DI) system for the approximately one hundred miles of freeways in the greater Seattle area. It will take a number of years to complete the total network system. The system topology, when completed, will provide transmission routing diversity and protection against single point equipment and cable failures. Figure 2.1 shows the location and status of all of the SC&DI projects in the Northwest region.

The communication system architecture allows connections between field devices and nearby communication hubs, which are then connected to the Traffic Systems Management Center (TSMC). Many circuits are collected at the hubs and then multiplexed before being transmitted back to the TSMC. This design reduces the quantity and expense of optical fibers, and associated equipment, including the conduit infrastructure. The hubs are located along a mainline route with an average interval spacing of approximately 7 to 9 miles.

The state-owned SONET communications system offers a Network Management System (NMS) which provides the hardware and software required to automatically administer and control the SONET transmission system supporting voice and data requirements. The NMS

Figure 2.1 WSDOT Northwest Region - SC&DI Projects (Part 1)

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Figure 2.1 WSDOT Northwest Region - SC&DI Projects (Part 2)

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is capable of alarm status reporting, system control and testing, determining fault locations, and circuit provisioning. The NMS capabilities can also be used for maintenance activities.

2.1.2 Olympic Region SC&DI

In the Olympic Region there are five existing VMS signs and a ramp meter. Two additional VMS signs are under construction. Communication with the five signs and the ramp meter is accomplished by means of dial-up lines leased from the telephone company. The design of an interim Traffic Management System (TMS) along I-5 from Fife south through Tacoma to the SR512 interchange has been completed, however construction has not yet been funded.

The interim TMS system as designed includes 21 ramp meters, 9 CCTV cameras, and several VMS, CMS and swing gates. Communication with the ramp meters will be via leased telephone company lines. A 23 gigahertz (GHz) microwave system with DS-3 transmission capability is to be constructed for transmission of analog video from the cameras. The communication system installed for this interim system is expected to be replaced with a fiber optic network in the future. Figure 2.2 shows the locations of the proposed ITS devices in the region.

2.1.3 South Central Region

The South Central Region is currently implementing a digital packet radio system for communication through the Snoqualmie Pass area on I-90. The project, known as Travel Aid, covers a 40 mile section of I-90 that experiences extreme weather conditions. The system consists of variable message signs (VMSs), variable speed limit signs (VSLs), and in-vehicle display systems.

The Travel Aid system includes 24 field sites, a control center, remote command centers, in-vehicle display units, communication systems, and portable transmitter units. The system is based on the Management Information System for Transportation (MISTâ). The MISTâ software, residing on a computer network at the Hyak Control Center, will communicate

Figure 2.2 Olympic Region SC&DI Project - Proposed ITS Device Locations

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with the field sites and SCAN+ computer to download data and weather reports respectively. The Hyak Control Center will communicate with the field sites through microwave radio links. Figure 2.3 shows the communication links to field sites.

2.1.4 Vancouver TMS Plan

There are limited communication networks in Vancouver for transmission of traffic management and control systems in the urban area. The state-wide 800 MHz trunked radio system is used for incident management and maintenance.

2.1.5 Spokane TMS Plan

A Traffic Management Systems (TMS) plan was developed in 1995 for the Eastern Region. The majority of the system is for traffic in and around Spokane. The plan calls for video detection to monitor traffic flow and for incident verification. The plan also discusses the use of Highway Advisory Radio (HAR) systems for traveler information The plan recommends microwave radio for transmission of video and data.

2.1.6 State-wide 800 MHz Radio System

WSDOT has a state wide 800 MHz trunked radio system for communication between the various construction and field offices. This system has 88 repeater sites and approximately 2000 users. Ultimately there will be approximately 3500 users. Installation is complete on the West side of the state and 60% complete on the East side. Installation is expected to be 95% complete by September, 1996.

The FCC has auctioned off frequencies in the 2 GHz band for personal communication services (PCS) with the understanding that the present owners of the frequencies will be “bought out” by the new owners of the frequencies. WSDOT has 4 paths and WSP has nearly 30 paths that are affected by the move. All microwave system plans, additions or

Figure 2.3 Travel Aid Project - Communications to Field Sites

(this figure <u>not</u> included in this electronic file) modifications to the system are on hold pending the outcome of negotiations of frequency buyout.

2.1.7 Microwave Radio

WSDOT has a state-wide medium capacity microwave radio system in operation. It is very limited in its capacity and connections with WSDOT offices across the state. The microwave system is used to connect WSDOT facilities to Washington State Patrol (WSP) radio sites for long distance communication. Figure 2.4 shows WSDOT microwave radio relay sites in the western region.

2.1.8 WSDOT MIS Leased Network

The WSDOT administrative department has an extensive network of leased lines connecting the regional offices to the Olympia Service Center. The leased line network uses T1 and 56 kilobytes per second (kbps) circuits to connect project engineers offices and WSDOT local offices to the regional offices. Currently, the department is using less than 20% of the network capacity. Figure 2.5 shows the configuration status of WSDOT's Wide Area Network.

The MIS department has a disaster recovery plan in place with hot standby facilities. There are alternative facilities available for all the major communication routes. These can be switched into place manually or in some cases automatically. Manual switchover is preferred at this time due to the nature of the data traffic. It is more cost effective to switch the circuits over during office hours as there is very little data traffic in the off-hours. There is a pilot program for video conferencing with the regional office in Spokane over the WAN that appears to be successful.

The WAN system is currently being used for administrative functions, e-mail, financial information, and transfer of CAD files, point of sale for WSF, and video. Voice

Figure 2.4 WSDOT Microwave Radio Relay Sites in Western Washington State

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Figure 2.5 WSDOT Wide Area Network

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communication between offices are provided by an independent leased network connecting PBX's at major offices.

2.2 WASHINGTON STATE PATROL SYSTEMS

The Washington State Patrol has an extensive VHF communication network for their operational communications requirements. This study, however, considers only their state-wide microwave radio network.

The existing microwave radio system operates primarily at 6 GHz with several links at 2 GHz or at 960 MHz. The WSP system runs north to south along I-5 and east to west along I-90. There are numerous spur routes to cover corridors for other state highways. WSDOT currently "leases" space at several of the WSP sites across the state. Figure 2.6 shows WSP's existing microwave links.

2.3 DEPARTMENT OF INFORMATION SYSTEMS (DIS)

The State of Washington Department of Information Systems communications network also consists of leased telephone facilities. The network includes facilities supported by inter-exchange common carrier companies. The DIS network is used to support voice, data, and video communications among the state offices. The existing system operates primarily at a data transmission speed of DS3. The westside connections and the eastside connection are using a transmission rate of SONET OC-1. The cross-mountain sections are DS3 connections. The DIS statewide network is depicted in Figure 2.7.

Figure 2.6 WSP Microwave System

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Figure 2.7 DIS Statewide Network

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SECTION 3 - COMMUNICATION TECHNOLOGIES

This section includes a concise overview of available communication technologies and protocols. A brief description of signaling protocols is also provided. Reliability and cost considerations are briefly discussed for several communication technologies. For a more detailed discussion of communications technology and its relationship to this report, see Section "A" of the Appendix.

3.1 COMMUNICATION PROTOCOLS

3.1.1 Analog

Analog transmission is a technique in which a transmission is conveyed by modulating (varying) the frequency, amplitude, or phase of a carrier signal. In modern communications systems, analog transmission is primarily used only for voice and selected video transmission.

3.1.2 Digital

Digital transmission can be applied to any communications requirements which includes digital data, analog voice and video signals. Digital transmission is less prone to degeneration of the signal and is very efficiently multiplexed. In addition, it can achieve higher transmission rates than analog. It should be noted that although digital transmission can support the same quality video transmission as analog, there is a substantial economic penalty associated with this transmission method.

3.1.2.1 North American Digital Hierarchy

North American Synchronous Digital Hierarchy is the standards used for digital transmission systems in the United States, Canada, Mexico, and Japan. The lowest rung on the hierarchy ladder is the DS-0 (DS-zero) rate, which is 64 kbps. DS1 facilities (24 DS-0 channels) are

1.544 Mbps circuits that can be used for voice, data, and video transmission. Table 3.1 shows different transmission rates for digital facilities according to this standard. DS1 and DS3 facilities are most commonly used.

Digital Facilities	Transmission Rates	Number of DS1 Equivalents
DS1	1.544 Mbps	1
DS2	6.312 Mbps	4
DS3	44.746 Mbps	28

Table 3.1 North American Digital Hierarchy

In concert with the North American Digital Hierarchy, older digital communications carrier systems and their protocols are still supported; such as “T” carrier systems. These systems are utilized to provide communications transport over copper twisted pair facilities.

Framing in the T1 environment is used primarily for signaling and maintenance. Signaling is needed to set up, maintain, and tear down connections in the public network. There are mainly two types of framing. D4 framing which consists of an “in-band” signaling technique that involves using designated bit slots within the user channels to convey signaling information; or Extended Superframe Format (ESF) which offers both in-band and out-of-band signaling. Unlike D4 framing, which only offers out-of-service maintenance, ESF offers in-service, non-intrusive diagnostics, testing, and performance measurement.

Table 3.2 shows different transmission rates for T-carrier facilities according to this standard. T1 and T3 facilities are most commonly used. Each T1 link offers a digital 1.536 Mbps transmission capacity and 8000 bps of overhead added for framing information.

Digital Facilities	Transmission Rates	Number of T1 Equivalents
T1	1.544 Mbps	1
T1C	3.152 Mbps	2
T2	6.312 Mbps	4
T3	44.746 Mbps	28

Table 3.2 T-Carrier Transmission Hierarchy

3.1.2.2 SONET

SONET (Synchronous Optical NETwork) is a transport network of synchronously multiplexed tributary digital signals. SONET protocols define a hierarchy of transmission rates, the basic signal rate being 51.840 Mbps, which is referred to as Optical Carrier Level One (OC-1). SONET defines a hierarchy of rates and formats to be used by vendors, carriers, and end-users for optical transmission at and above the 51.840 Mb/s rate for Optical Carrier Level One (OC-1). It should be noted that the electrical equivalent of an OC-1 signal is known as a Synchronous Transport Signal-Level 1 (STS-1{ 51.840 Mb/s}) and is the highest electrical signal rate in the synchronous digital hierarchy. The 51.840 Mb/s rate is derived from a DS3 signal (44.736 Mb/s rate) plus overhead control and maintenance channels. Consequently, in the SONET realm, OC-1 is an acronym for the ability to carry the equivalent of one DS3 channel (≈45 Mb/s).

SONET grows in multiples of the basic signal into the multi-gigabit range. A SONET architecture has the ability to add/drop signals on a per channel basis. Table 3.2 shows examples of different transmission rates.

SONET Levels	Transmission Rate	DS1 Equivalent	DS3 Equivalent
OC-1	51.840 Mbps	28	1
OC-3	155.520 Mbps	84	3
OC-12	622.080 Mbps	336	12
OC-48	2488.320 Mbps	1344	48

Table 3.3 Transmission Rates for SONET Networks

The basic signal can be divided into a portion that is assigned for transport overhead and a portion that contains the payload. The overhead bits can be used for many purposes, such as maintenance, user channels, frequency justification, channel identification, and growth channels. In addition, the payload envelope contains path overhead whose functions include a path trace that ensures receiver to transmitter terminal connection, a path error monitoring function, and other similar control functions.

It is worth noting that a rapidly emerging communications technology that leverages the SONET transmission capability is asynchronous transfer mode (ATM) which uses a transmission rate of 155.520 Mbps. When SONET is used as the long haul transmission for this technology the designation for the transmission rate is OC-3c which denotes that the transmission is not subdivided into discrete, fixed bandwidth channels because ATM provides a flexible bandwidth capability based upon demand.

3.2 COMMUNICATION TECHNOLOGIES

3.2.1 Copper Cables

3.2.1.1 Description

Copper cable communication systems use cables consisting of insulated solid copper conductors that are twisted into pairs to minimize cross talk. They are wrapped with a protective material, covered with a shield to reduce electromagnetic interference, and then wrapped with a protective jacket. Cable intended for underground use is flooded with a vitreous gel to inhibit water migration. The primary placement for copper cable is aerial, direct-burial, or in underground conduit. Conduit affords the cable added protection and simplifies the replacement or addition of cable.

3.2.1.2 Reliability

Several considerations for using copper cables for signal transmission are:

- Rapid attenuation, phase shift, characteristic impedance, and signal leakage. In addition, it can increase cross-talk and cable noise by introducing reflections and variable attenuation.
- Copper cables are vulnerable to EMI and RFI interference.
- Copper cables installed in underground ducts are vulnerable to dig up.
- Aerial installations are vulnerable to vandalism and storms.
- Cable buried directly is vulnerable to rodent attack.

3.2.1.3 Costs

Installing a copper cable communication system generally requires a high capital cost and a low operating cost. Installation cost includes trenching and backfilling costs, cable pulling costs, splicing, cable terminating, and material costs. In addition, there are costs for installing conduits, cables, splice boxes and communication cabinets.

3.2.2 Optical Fiber

3.2.2.1 Description

Optical fiber systems use glass fiber for digital transmission of communication signals. Optical fiber systems have a tremendous bandwidth capacity, much of which is not utilized by today's communication equipment. There are two basic types of optical fiber cable: single mode and multi mode. Single mode cable has greater bandwidth and signals can travel longer distances without appreciable signal degradation. Single mode cable is preferred in the transportation industry.

3.2.2.2 Reliability

Optical fiber transmission systems are highly reliable. They are essentially immune to RFI (radio frequency interference) and EMI (electromagnetic interference) induced noise as well as lightning strikes (except direct hits) and power cable faults. In addition, it is very difficult to intercept optical signals making it a very secure means of communication. With fiber optic transmission, there is no noticeable delay in signal propagation.

Optical fiber cables installed underground are vulnerable to dig-ups and rodent attack. Moisture and dirt can cause attenuation of the communication signal if permitted to get into optic connections or splices.

3.2.2.3 Costs

The cost of installing optical fiber cable is similar to that of copper cable with a few important exceptions. Some of the installation costs involved are trenching and backfilling costs, conduits and cable installation costs. But, cable pulling and splicing costs for optical fiber are significantly higher than for copper. Transmission equipment is also more expensive. However, in the area of long-haul systems, an optical fiber system is more cost-effective than copper cable as it provides larger bandwidth capacity, superior transmission quality, and longer spacing between repeaters.

3.2.3 Microwave Radio

3.2.3.1 Description

Microwave radio technology involves point to point radio communications operating in those portions of the electromagnetic spectrum occupying frequencies of 1 GHz to 30 GHz.

Microwave systems must have a clear line of sight between the transmitter and receiver including an area around the center line of the beam called the Fresnel Zone. Objects penetrating the Fresnel zone cause wave reflections that cancel out most or all of the transmitted signal.

3.2.3.2 Reliability

The principal communication reliability problem with a microwave radio relay system is RF signal fade. Several factors can cause fading of received signals. Heavy rain can attenuate and completely eliminate the received signal at 23 GHz for 10 to 15 minutes. Rain will create sporadic fading as long as it continues to fall within the line-of-sight path. When selecting a path the growth of trees or the possibility of a building being constructed in the signal path in the future must also be considered.

3.2.3.3 Costs

Some of the costs associated with installing a microwave system includes:

- Site development costs, such as grading, constructing an access road, constructing a building to house the equipment, and electric utility construction.
- Materials and installation of equipment.
- FCC licensing.
- Power costs and maintenance costs.

3.2.4 Satellite Radio

3.2.4.1 Description

Satellite radio communication systems involves using geosynchronous communications satellites to relay radio signals from one sending earth station to another or multiple earth stations. Satellite systems are used primarily for voice and data communications. Depending on the region, data transfer rates range from 6.4 kbps to 21.33 kbps and voice coding rates range from 4.2 kbps to 16 kbps.

3.2.4.2 Reliability

Network transmission failures are unlikely with satellite systems. However satellite paths are subject to several forms of attenuation, interference, and delay which might affect the use of the channel. Primary sources of problems are:

- Attenuation of the signal due to the distances involved or to atmospheric absorption (rain/fog).
- Obstruction of the signal by terrestrial objects, or even by rainfall.
- Interference by satellite transits close to the solar disk or through competing microwave use.
- Propagation delay, caused by the extremely long paths of the satellite environment. The effects of satellite transmission delay is very significant in data transmission.

3.2.4.3 Flexibility

Satellite radio provides the flexibility of point-to-multipoint transmission. Satellite antennas are relatively easy to install and enable any ground station to become a network node. This makes satellites ideal for reaching remote or thinly populated areas. Satellites can be easily reconfigured while in orbit to cover different geographical areas.

3.2.4.4 Costs

The cost of launching a satellite into orbit is the most significant expense involved in satellite communications. Operating costs are also high. Most users lease bandwidth on an existing satellite system, however, lease costs can also be high. Cabling, trenching and backfilling costs may be required to connect the satellite communication network to a ground station.

3.2.5 Wireless Services

3.2.5.1 Cellular

Cellular radio is a technology for advanced mobile telephone service in which a geographic area is divided into hexagonal cell sites that fit together to form a honeycomb. A central switch manages the transfer of mobile phone calls from one cell to another as a caller moves through a geographic area. The cellular design provides the flexibility of dividing key cells into a number of small cells to adapt to changing customer demands.

The cost of obtaining a cellular connection from a cellular service provider involves an activation charge, a monthly charge plus airtime charges. Airtime charges for a continuous connection can make the use of cellular radio prohibitive. For a connection that is used sporadically, perhaps once an hour or only when conditions need to be changed, cellular radio may be a preferred choice. Installation of a cellular connection is very easily accomplished. There is no trenching or extensive cabling required.

3.2.5.2 Trunked Radio

In multi-channel trunked radio services all users of a radio system can access all available channels; so, even when several assigned channels are busy, a system computer is often able to locate a free radio channel and automatically switch the dispatcher to that unoccupied frequency. As a result, dispatchers have to wait less often to transmit their messages, and the blocking probability-the likelihood that a free channel will be unavailable-is reduced. Trunking a multi-channel radio system increases the efficiency of the radio system by dynamically managing the use of the radio channels.

3.2.5.3 Private Line Mobile Radio

In private line mobile radio services, frequencies are set aside for direct use by specific groups who can transmit over their radio channels without incurring airtime charges. When these radio services use their single radio channels, there are many instances when dispatchers have to wait to transmit messages because the channel is occupied by another dispatcher that shares the same frequency assignment. Even though there are times when adjacent radio channels are free, they cannot be used by dispatchers on the congested channel because they have not been authorized access.

The availability of frequencies for licensing in the 800 or 900 Megahertz (Mhz) frequency bands is decreasing rapidly. In the Seattle area frequencies at 800 Mhz are virtually unavailable while 900 Mhz frequencies are difficult to obtain. The FCC is considering reducing the spacing required between channels to increase the number of frequencies available for licensing.

3.2.6 Leased Telephone Company Lines

3.2.6.1 Dial-up Lines

Dial-up (switched) lines may be leased from the local telephone company. Data transmitted over switched lines is routed through the public telephone switched network as would a normal telephone call. It is subject to the same queuing delays and network perturbations that private subscribers experience.

The costs involved in leasing a dial-up line from the telephone company include installation and monthly charges. There are trenching, backfilling and cabling costs for the connection to the telephone company.

SECTION 4. – FEDERAL LEGISLATION AND REGULATORY ISSUES

The Telecommunications Act of 1996 (the "Act") makes sweeping changes to regulation of telecommunication services throughout the country. The following information provides some highlights from the Act that may be of interest to State transportation officials and major telecommunications users.

4.1 Connectivity

In general, all telecommunications carriers were ordered to link their facilities and equipment, directly or indirectly, with one another. Any new equipment or functions has to comply with federal guidelines for network interconnectivity and access as outlined below.

Specific requirements for local exchange carriers (this can be either the local monopoly telephone company or a competitive access provider) provide that incumbent telephone companies are must allow competitors, on request, to connect with their networks at any technically feasible point in order to complete calls. The connection has to be at least equal in quality to what the incumbent provides to itself or any other company.

Incumbent companies also are required to give competitors access to individual elements of their networks, such as a particular telephone line or switch.

The fees charged for connecting to the incumbent's network or using individual elements has to be just, reasonable and nondiscriminatory. Such a fee will be considered just and reasonable if it is based on cost, although it could include a reasonable profit.

Each incumbent is ordered to give reasonable public notice of any changes in its network that could affect a competitor's use of the network. With limited exceptions, an incumbent also has to allow competitors to install their equipment inside its facilities.

All local exchange carriers are required to let their services be resold without unreasonable conditions. Incumbent carriers have to go one step further, offering resellers their services at wholesale prices; which the law defines as retail rates minus the amount attributable to marketing, billing and other obligations assumed by the reseller. State regulators are allowed to prohibit resellers from buying one category of service and marketing it to a different category of customers.

Incumbents and their competitors alike are required to provide dialing parity and, to the extent technically feasible, number portability. They also have to make telephone numbers, operator services, directory assistance and White Pages listings available to all carriers without discrimination or unreasonable dialing delays.

All local exchange carriers are ordered to compensate one another for the calls made between their networks. The charges have to be reciprocal and roughly equal to the added cost of completing a call. Alternatively, two carriers could agree not to exchange any money, as in the "bill and keep" systems used by some neighboring telephone companies.

Finally, the law requires both incumbents and competitors to negotiate the terms of an interconnection agreement in good faith. All interconnection agreements are required to be reviewed by state regulators. Any agreement reached through negotiation has to be approved by the state unless it discriminates against a carrier that is not a party to the agreement or it is inconsistent with the public interest.

4.2 Rural Telephone Company Interconnection

The interconnection requirements are waived for rural telephone companies unless state regulators find that a competitor's proposal for interconnection or resale is technically feasible, is not economically burdensome and will not reduce the availability of telephone service. State regulators are given 120 days after a competitor proposes to enter a rural market to decide whether to end the exemption. A rural telephone company that enters the cable TV market after Feb. 8, 1996, however, cannot claim the exemption to block a local cable TV company from offering telephone service.

Local telephone companies not affiliated with one of the major telephone companies are allowed to ask state regulators to suspend or modify the interconnection requirements. The state will have to grant the request, at least temporarily, within 180 days if it is in the public interest and would protect consumers or the telephone company.

4.3 State Review of Bell Interconnection Terms

The Act permits a Bell company to file with state regulators a statement of the terms and conditions it generally offers for interconnection or resale. The state could disapprove such a statement unless it meets the Act's interconnection requirements and pricing standards, as well as FCC standards. States also can impose additional requirements, such as standards for the quality of service, as long as they do not conflict with the Act or effectively bar competition.

States are given 60 days to review a statement unless the Bell company agrees to an extension. If a state does not complete its review in time, the Bell company's statement will go into effect on an interim basis until the state takes action. Even if a state approves its statement of terms, a Bell company will still have to negotiate in good faith with any carrier seeking to interconnect.

State regulators have to make a copy of each approved statement available to the public within 10 days of its approval.

4.4 Plant Facilities

Telephone service providers have to make their poles, underground conduits, and other rights of way available to one another. However, cable companies that provide telephone service are required to pay more for the utility-company poles they use. The FCC has been ordered to adopt regulations by Feb. 8, 1998, to rewrite the cost-sharing formula for telecommunications carriers that use an utility's poles, ducts, conduits or rights of way. Those regulations are to become effective Feb. 8, 2001. Any increase in rates mandated by the new regulations has to be phased in over the following five years.

The previous formula, set by Congress in 1978, divided the costs of a pole according to the percentage of "usable space", the space where companies attached their wires or antennas, taken up by each company's attachments. The new formula will divide the cost of the usable space among all companies offering telephone service, other than the incumbent telephone company, according to the percentage of the space they occupy. In addition, two-thirds of the rest of the cost of the pole has to be divided equally among those users. Utilities that provide telephone service have to charge themselves or their telephone affiliates the appropriate share of the costs.

Cable companies and telecommunications carriers have to be given access to poles, ducts, conduits or rights of way on nondiscriminatory terms. Electric utilities are allowed to waive this rule, however, for the sake of safety, reliability, capacity or engineering reasons.

The owner of a pole, duct, conduit or right of way has to notify all users in writing of any planned modifications, giving them a reasonable opportunity to modify their attachments. Users that do so have to pay a proportionate share of the cost of making the pole accessible to them. Users will not have to pay, however, for any rearrangements or replacements required if the pole is modified or a new attachment added by the incumbent.

4.5 Interconnection by Long-Distance Companies and Information Services

Until the FCC adopted new rules, local phone companies are required to continue giving long-distance companies and information services equal and non-discriminatory access to their customers.

4.6 Telephone Numbers

The FCC was ordered to shift the job of assigning telephone numbers from the incumbent telephone companies to independent entities. The costs of this shift have to be shared by all telecommunications carriers.

4.7 Removal of Barriers to Entry

In general, all state and local laws, regulations or legal requirements that bar competition in telecommunications are nullified.

If after notice and an opportunity for public comment, the FCC determines that a state or local government has permitted or imposed any statute, regulation, or legal requirement that violates the forgoing the FCC can preempt such statute, regulation, or legal requirement to the extent necessary to correct such violation or inconsistency.

4.8 Long-Distance Service

For the most part, the Act sets conditions for the seven regional Bell telephone companies and their affiliates to offer service across their local boundaries, or "LATAs" (Local Access and Transport Areas). These conditions replace the strictures of the 1982 consent decree that broke up AT&T. Under the consent decree, a Bell company was forbidden to offer any service across LATA boundaries unless there was "no substantial possibility" of the Bell company using its dominance over the local exchange to impede competition in the inter-LATA market. The Justice Department and federal courts interpreted that restriction to mean that a Bell had to face significant competition locally before it could offer long-distance service.

Bell companies are immediately allowed to perform certain functions across their LATA boundaries that are incidental to specific audio, video and telephone services. The list includes audio, video or interactive programming that a Bell company offers to subscribers; alarm monitoring; interactive video and Internet service to schools; mobile phone and paging services; voice mail; and signaling between networks. The FCC is directed to ensure that the Bell's telephone customers and competitors are not harmed by this provision of incidental services.

The ACT requires a Bell company to pass a series of tests before it can offer long-distance service in a state where it provides local phone service. First, a Bell company has to face competition. Specifically, the Act requires a Bell to enter at least one state-approved interconnection agreement with a company that provides local telephone service to businesses and homes using predominantly its own equipment. That agreement has to satisfy a 14-point "competitive checklist" designed to measure the Bell's progress in opening its network to competitors.

To comply with the checklist, the agreement has to meet the Act's standards for interconnection, access to individual network elements and reciprocal compensation, even if the agreement has been negotiated voluntarily. Specific, key elements of the Bell's network has to be provided on an individual basis, along with non-discriminatory access to emergency calling services, directory assistance, data bases for call routing, operator services and telephone poles, conduits or rights-of-way.

The checklist also demands that the Bell provide number portability, first on an interim basis and later in whatever manner the FCC requires, and access to the services or information needed to achieve dialing parity. The Bell company also has to give its competitor(s) phone numbers to assign to customers and list those customers in its White Pages.

If no would-be competitors emerge in a state in the first seven months or more after enactment of the Act, a Bell company can wait three months and then file a statement of the terms it generally offers for interconnection. The statement can be used in lieu of an interconnection agreement if it is approved by state regulators and complies with the 14-point checklist. If a competitor requested interconnection but failed to negotiate in good faith or abide by the implementation schedule, the Bell can proceed as if it had not received that request.

A Bell also has to set up a separate affiliate for its long-distance activities. Then a Bell has to win the FCC's permission to enter the long-distance market. The Act allows the FCC to deny the Bell's application for any of three reasons. These are:

- The Bell did not have a qualifying interconnection agreement or statement of terms
- It did not comply with the requirements for a separate affiliate, or
- Its move into long distance would not be in the public interest.

Before making its decision, the FCC has to consult with state regulators to verify the Bell's compliance with the interconnection requirements. It also has to consult with the Justice Department, whose antitrust division has reviewed all previous Bell requests to enter new markets. The Act directs the FCC to give substantial weight to the Attorney General's recommendation, although it did not make that recommendation binding on the FCC.

The FCC has a 90-day deadline for issuing a written decision that states a reason for approving or denying the Bell application. Also, the FCC is not allowed to expand or reduce the checklist.

After winning approval, the FCC can revoke its approval or take other action against a Bell company if the Bell company stopped meeting any of the Act's conditions.

4.9 Public Rights-of-Way

The authority of state and local governments to manage public rights of way is not dramatically affected by the Act. State and local governments are allowed to continue imposing fees for using the rights of way, but only if the fees do not favor or discriminate against individual companies. Also, the fees have to be made public.

It should be noted that currently it is unclear how state regulations limiting access to highway rights-of-way for occupancy by telephone companies may be construed in light of the requirements of the Act set forth in 4.6 above.

4.10 Telephone Service by Power Companies

In general, registered utility holding companies are allowed to offer telecommunications and information services if they establish subsidiaries that provide only telecommunications, information, or related services. The FCC must determine within 60 days that a subsidiary meets the Act's requirements. The Act gave the FCC until Feb. 8, 1997, to develop rules for these proceedings.

The Act gives state and federal regulators authority to guard against direct or indirect cross subsidizing within a holding company. State utility regulators can bar a holding company’s power subsidiary from selling assets to its telecommunications subsidiary if those assets have been paid for by the power company’s customers. Regulators have the option of preempting any purchases that a power subsidiary makes from a telecommunications subsidiary.

State regulators and the Federal Energy Regulatory Commission are given the power to review transactions between a power subsidiary and a telecommunications subsidiary to determine whether the costs should be included in the power company's rates.

The Act also gives state regulators the power to inspect accounts and order annual, independent audits as needed to oversee the effect of a telecommunication subsidiary's activity on a power subsidiary's rates.

A holding company is permitted to acquire or finance a telecommunications subsidiary without prior approval from the Securities and Exchange Commission (SEC). The Act does not, however, stop the SEC from enforcing existing securities laws. The SEC is given the power to compel holding companies to report on any telecommunications related activity that could affect the financial health of their systems.

A holding company's power subsidiary is forbidden to issue securities, provide collateral or assume liabilities for an affiliated telecommunications subsidiary as long as the power company's rates are regulated by the state.

An utility holding company's telecommunications subsidiary is required to comply with state and FCC regulations.

4.11 Regulatory Relief

The Act orders the FCC to forbear from enforcing any regulation or provision of the federal communications law if it no longer was needed to protect consumers or ensure just, reasonable and nondiscriminatory prices or practices. Before forbearing, the FCC had to find that not enforcing the regulation or provision was in the public interest. That test could be met if the FCC found that forbearing would promote competition.

Telecommunications carriers or groups of carriers are allowed to petition the FCC for forbearance. The petition would be granted automatically if the FCC did not act within one year, although the FCC was avowed to grant itself a 90-day extension.

4.12 Cellular Antenna Siting

The Act limits the power of state and local governments to control the placement of antennas and other facilities for cellular phones and similar wireless services. Although traditional local zoning powers are preserved, state and local governments are forbidden to regulate the placement, construction or modification of wireless facilities in a way that effectively prohibits such services. State and local governments also are barred from unreasonably discriminating among the facilities proposed by companies providing competing services. They are required to act within a reasonable period of time on any proposal to build or modify a facility, or else the FCC can intervene. Any denial has to be in writing and supported by substantial, on-the-record evidence, and appeals are to be expedited.

State and local governments are not allowed to regulate wireless facilities based on the effects of their radio frequency emissions; the FCC is given exclusive jurisdiction over that issue. The Act orders the FCC to prescribe rules on radio frequency emissions by Aug. 6, 1996.

The federal administration is given until Aug. 6, 1996, to prescribe a way to make federal property and rights of way available for wireless telecommunications facilities. However, the federal government is allowed to charge reasonable fees for the use of its property or rights of way.

SECTION 5 - STATE-WIDE COMMUNICATION NEEDS

This section addresses the communication network requirements for support of ITS applications and intra-departmental communications as well as for other state agency communications. Technology issues include communication between the vehicle and traffic control infrastructure and the unique video requirements of WSDOT. This view is influenced by the significant number of WSDOT research and development projects currently underway.

Based upon the information gathered regarding WSDOT's current operational practices and operational systems the following text describes in general terms the present and foreseeable future communication systems requirements.

WSDOT communication needs can be broken down into two major areas for discussion, ITS and traffic control, and administrative communications.

5.1 ITS AND TRAFFIC CONTROL

The currently forecasted implementation of ITS and traffic control systems occurs primarily in the Puget Sound area between Seattle and Tacoma. The Northwest Region is building an extensive optical fiber network in the greater Seattle area to support ITS applications. The North Seattle ATMS (NSATMS) project will connect WSDOT to many of the City and County agencies and Transit by means of leased telephone lines, the City of Seattle's optical fiber system (Department of Administrative Services) and the WSDOT optical fiber system.

In the Olympic Region, a TMS system using dial-up communications for data and a microwave network for video has been designed for the Tacoma area. Construction of the Tacoma system has not yet been funded.

A study is underway to develop a 20 year plan for implementing ITS and traffic control systems for the I-90 corridor from Seattle to Spokane and for the I-5 corridor north from

Seattle to the Canadian border. Plans for development of ITS systems are also being discussed for the urban area around Spokane. The need for broadband communication along these two corridors will become very prevalent in the near to mid-term. Plans for ITS systems on these major corridors and in the urban areas include design of VMS and CMS signs, traffic operations centers in urban areas, video surveillance, Highway Advisory Radio and other elements of traffic control for incident management.

Based upon the currently forecasted introduction of additional ITS services and the increasing density of population in the state, it is likely that broadband communication requirements will increase dramatically over the next two decades to provide support for standard video surveillance as well as high speed communication with traffic control devices and sophisticated databases. Additionally, it is probable that wireless communications usage will increase in support of emerging ITS features in the areas of incident management, in-vehicle traveler information, ride sharing, electronic toll collection, as well as point of sale applications to support multimodal travel. Communication requirements will exceed the T1 level on major corridors; such as I-5 and I-90 before the end of the near term period.

There are many corridors in Washington State that are used primarily for recreational access or for tourism. The ITS applications in these areas include trip planning, safety concerns, notification of traffic delays and dangerous conditions. These corridors will have limited needs for broadband communications in the mid- to long term. There are many rural corridors throughout the state with little need for wideband communications. The ITS applications in these rural areas will primarily include notification of safety concerns, traffic delays and dangerous conditions. These applications will have needs for narrow bandwidth systems that could be served by one or two leased dial-up lines.

5.1.1 Traffic System Management Center Requirements

The Northwest Region's Transportation System Management Center (TSMC) is the focal point for all traffic control information in the region. As the system expands, the communication requirements between the TSMC and field devices will continue to grow. Future TSMC communication needs will increase as connections to other regional offices are introduced. The TSMC will require broadband digital connections to the other regional offices as well as wideband digital communications to the Olympia Service Center and Washington State Ferries. Connections to City and County agencies as well as transit companies will be required to support an integrated regional ITS operations. A video feed, currently supported by US West, is provided to the media for updates on traffic conditions. The total communication transmission capacity requirement of the TSMC will likely approach the SONET OC-48 level within the next 20 years. This forecast assumes that the present analog video system will migrate to digital video and will be placed on the SONET communication network.

Additional traffic control centers will be desirable in Vancouver and Spokane in the next twenty years. Another potential traffic control center location is in the Bellingham area for traffic to and from Canada. The traffic control centers in these locations will have similar communication requirements to those of the TSMC in the Northwest Region. Due to the less dense communities the data transmission requirements will be somewhat less than that for Seattle.

5.2 INTRA-DEPARTMENTAL AND ADMINISTRATIVE COMMUNICATIONS

WSDOT has many offices state-wide that need to communicate with their regional office, the Olympia Service Center and with each other. At the present time this communication is achieved by a network of leased lines from the telephone company. The majority of these lines have been upgraded to T1 in the last year. These lines are currently being used at under 20% of their capacity. A separate leased line network is being used for inter-office voice communication. Administrative communication requirements that impact the communication network will be the support of video conferencing service and high-speed local area networks that may be connected to the wide area network. Given the rapidly emerging multimedia technology, as well as accelerating use of electronic storage and retrieval of documents, it is inevitable that in the interest of efficiency, office automation applications will be upgraded; which will cause a corresponding upgrade in the speed of office LANs. Office LANs at Northwest and Olympic region have been upgraded to 100 Mbps this year.

The primary links required for administrative communications are from each of the six regional offices to the Olympia Service Center. Secondary links extend from each regional office to the associated local offices, these include maintenance shops as well as construction project offices. The need for increased bandwidth in these links will be exacerbated by the increased use of office automation applications, high speed LAN's and video conferencing.

The use of leased lines leaves WSDOT dependent on the telephone company for system quality and costs. The leased line rates will go up from year to year making it difficult to budget for the long term. The maintenance of the lines including restoration of service will be according to a schedule set by the telephone company rather than according to the needs of the DOT. Quality of service may be compromised depending on the system configuration that is determined by the telephone company. Quality and availability of service will also be impacted by the data needs of other users of telephone company services.

The capacity of the existing digital network will not be adequate as more and more office applications are sent over the digital wide area network. Applications will require higher data transmission rates, which will use more of the bandwidth. The need for digital communication connections between offices will increase in the future so that the current capacity of these lines will become inadequate in the near to mid-term.

5.3 OTHER AGENCY REQUIREMENTS

The provision of communications support to other state or local agencies will place additional demands on the communications network. In addition to the above WSDOT traffic and administrative demands, a need for greater network capacity will be realized should WSDOT elect to support the communication needs of the Department of Information

Services (DIS) and other state agencies. DIS communication needs will, in general, be point to point routes between state offices and the state offices in Olympia.

The provision of communication support to other City and County agencies may place a modest demand on the communication network. The majority of City and County communication that would be transmitted over the WSDOT network would be communication between that agency and another agency or the State governmental offices in Olympia. The specifics of the level each corridor is effected would need to be studied on a corridor by corridor basis. However, as the DIS, MIS and other agency communication needs are met, transmission capacity in the Olympia area will certainly increase to a SONET level of OC-48 over the next 20 years.

5.4 FUTURE EVENTS THAT MAY IMPACT THE COMMUNICATION NETWORK

There are several future events that may impact the communication network established by WSDOT for inter and intra- agency communication. One of these is the legislation discussed in Section 4, the Telecommunications Act of 1996 that is currently being implemented by the Federal Government. The introduction of Public/Private partnering (resource sharing) for implementation of communication systems may have a profound and widespread effect on the type of networks being developed by WSDOT if the introduction of this concept is relieved of current state regulatory and statutory restrictions, as well as any potential impediments introduced by the Telecommunications Act.

Another future event is the development of cost-effective alternatives for analog video. Digital video systems, as they are available today, are not a cost-effective alternative to analog video transmission. As cost effective digital video equipment becomes available and systems convert to digital video, more and more bandwidth on the digital communication network will be required for this type of transmission.

The continuing widespread implementation and use of ITS systems for driver information and traffic control will have a significant impact on the communication network. ITS applications will require communication from each field device to a control point for monitoring and control. ITS systems will continue to play a large role in providing traffic control, safety and information.

The need for real-time information in ITS applications is beginning to grow. As more information becomes available the demand, from the public and users, for real-time information will become even more imperative. This will impact the communication network as in many cases the transmission speed of the communication media determines the feasibility of providing real-time data. For transmission of video in particular the bandwidth and speed of the network is critical. If the bandwidth is not adequate the time required to transmit a video image may make the image unusable by the general public.

SECTION 6 - STRATEGIES FOR THE STATE-WIDE SYSTEM

This section will discuss strategies for implementation of a state-wide network and some of the financial and technical considerations for selection of a strategy. Several state-wide strategies will be presented and evaluated, and a recommendation made.

6.1 NETWORK STRATEGIES

There are a number of strategies that can be used for implementation of a state-wide communication network. Some of these strategies can be combined to provide even more flexibility in the overall structure of the network. These strategies include a mix of technologies such as optical fiber systems, microwave radio systems, satellite radio systems, copper cables and wireless services such as cellular, trunked radio or FM radio. One strategy is to provide a communication network built and operated by WSDOT. A second strategy is to lease facilities from a telephone service provider. Other strategies include leasing space on systems owned and operated by other State owned agencies, sharing facilities with other state agencies, or developing collocated facilities. Another strategy would be to consider developing communication facilities jointly with organizations in private industry.

A state-wide system will be most effective using a range of strategies. The method of communication for individual areas should be compatible with the communication needs in that area. For example, in remote areas where communication with a device is rarely required, a dial-up line leased from the telephone company may be the best solution whereas in a main cross-state corridor, where there are a number of devices that require continuous communication, an optical fiber may be the prudent choice.

6.1.1 Network Requirements

The communications network must have the capability to provide communications support at the locations and in a form that is compatible with the provision of ITS devices and services in the various highway corridors. For the most part, devices will be located adjacent to or near the state highway system as well as within WSDOT buildings which house operational centers and information systems associated with the various ITS services. Therefore, it is implicit that the backbone or mainline of the communications network must be located contiguous to or closely adjacent to the I-5 corridor. Additionally, the network should provide access points for network users to easily and economically utilize the facilities and features provided by the network.

The communications network must be highly reliable. A loss of the communication link will cause contact to be lost with the ITS device. Some devices will remain in their last state, however some devices will no longer function. For example, ramp meters will continue to cycle at their last setting but video from the freeway CCTV cameras and incident detection information will be lost. Data collected by the ITS devices will also be lost.

6.1.2 Capabilities

The communication network must be capable of supporting current and future ITS technologies. Most notably, the communication network will include the following capabilities:

- Support broadband transmission associated with video and wideband data communications services.
- Provide a means to easily reroute communications traffic to available alternate transmission facilities.
- Provide a means to easily send a signal to multiple points (broadcast) within the network.
- Provide an abundance of network interfaces so as to support a wide array of equipment.
- Conform to recognized industry standards.

6.2 FINANCIAL CONSIDERATIONS

The communications network must be economically prudent and constructable in segments. Although there may be funding alternatives for the development of the communications network under a public/private partnership arrangement, it is recognized that funding will likely be provided from public funds. Therefore, because the network will likely be constructed by a public agency, its cost must be defensible under scrutiny. Additionally, the network must be capable of being constructed in segments because funding will be spread over a period of years. However, it is still worth noting that an emerging phenomenon is the cooperation of public agencies and private companies in the construction of communication infrastructure in state highway rights of way that can be used to support both ITS applications of the DOT and the profit interests of the private partner. This resource sharing concept will optimize the use of the public right of way as well as mitigate the cost to the public agency to construct a state of the art communication system.

There are some financial considerations when selecting a strategy for each area of the state. These are discussed below:

Accessibility to telephone company lines- If the telephone company has facilities in the vicinity, the costs to connect to state devices or facilities will be much less than if new telephone facilities have to be installed.

Access rates - The access charges for use of a telephone company line has a direct correlation to the amount of time the communication line is accessed and the capacity of the line. If a great deal of data is to be transmitted every day a telephone company line may not be a cost effective choice.

Bandwidth Required - The telephone company charges for a high capacity line are significantly greater than those for a simple dial-up line.

Distance between sites - If the distance between field devices is long, an optical fiber or a copper cable may not be the most cost effective choice due to the cost of installation on a per location basis.

Maintenance - If the system is owned and operated by the state, the cost of maintenance is a very significant input into choice of strategies. This would apply to routine and emergency maintenance as well as system upgrades. The costs for maintenance will include staffing and training as well as equipment and related support costs.

Cost of construction - The cost of construction will play a role in selection of strategy. In addition to equipment procurement and labor, costs to consider will include permitting, environmental mitigation and system design.

6.3 TECHNICAL CONSIDERATIONS

Technical considerations regarding the selection of network strategies include:

System Capacity - Bandwidth requirements will determine what type of service will be required and will have a significant impact on the technology chosen. It is important that the network protocol and system hardware architecture should allow the system capacity to increase through the addition of devices to the network without adding physical links or redesigning the system. This may not be the case in areas where additional high bandwidth lines are required. The telephone company may not have facilities available in certain areas for high bandwidth service. If the bandwidth requirement is very small it will not be cost effective to install high bandwidth facilities.

System Reliability - A strategy for a communication link for a critical application will require some consideration for redundancy, standby systems or system back-ups. No specific parameters for system availability have been defined. However, there has been a general indication by the agency staff members that were interviewed that highly reliable service is a requirement. To meet the requirements for "fail safe" service availability, route diversity is required in a system design. One way this can be achieved is by connecting the mainline transmission line to a TSMC (or some other significant hub point) in a loop configuration or providing each communications node with two physically separated routes to a TSMC.

System Quality- The transmission quality of the communication system depends on the quality of the received signals. The received data should have low error rates, video signals should be adequate for definition of vehicles, and voice transmissions should be undistorted. If the system is to be installed in an area of high electromagnetic or radio frequency interference the anticipated quality of the system needs to be considered.

System Flexibility - The need for the system to expand in a certain area as ITS applications or administrative applications are added, should be considered when choosing a strategy.

Ease of Construction- Availability of materials, right of way, access for trenching, access to power, and environmental and permitting concerns all have an impact on the feasibility of construction.

Accessibility to existing communication sites - In some areas access to Washington State Patrol or to other existing radio sites may make one strategy more effective than another.

6.4 STRATEGIES FOR CONSIDERATION

6.4.1 State-owned System

One strategy for consideration is for WSDOT to develop a totally state-owned system. This would mean that every road-side field device and every WSDOT office would use state-owned facilities to meet the communication needs.

This strategy could be met by using an optical fiber based system in the I-5 corridor from Marysville to Olympia and digital microwave from Olympia to Vancouver as recommended in technical memorandum Number 5. Other corridors would use digital microwave radio or optical fiber as suited the requirements of each segment. Generally speaking, the urban areas would use optical fiber and the rural, less dense areas would use digital microwave radio. In some areas other wireless systems may provide the necessary communications. For example, in the Snoqualmie Pass area an 800 Mhz packet radio system has been installed for a local driver information system.

The advantages to a system of this type are:

- WSDOT would have ultimate control over how the system is designed, installed, maintained and operated.
- WSDOT would not have to worry about usage rate increases and would be able to prioritize maintenance of the system according to their own needs.
- WSDOT would have total freedom to make changes to the network to enhance system performance or capacity.

The major disadvantages are:

- WSDOT would have to provide funding for the system design, installation maintenance and operation. This may make it very difficult to have the system designed and installed in a timely fashion as funding for WSDOT facilities are obtained through the legislative process.
- Funding for operation and maintenance would have to be obtained on a regular basis.
- There is a trade-off on system flexibility as the telephone company very often will already have facilities in an area where expansion is desirable.

There are several managerial considerations for a solely owned state wide WSDOT system. One of these is the availability of staff to operate and maintain the system. The staff would have to be located across the state or be prepared to travel all over the state. The staff would have to be trained to operate and maintain all the systems installed in the state-wide system. Another managerial consideration is the assignment of space on the network. One entity in the state would oversee the network to ensure that there is available bandwidth for all the uses required by WSDOT and any other agencies that would like to access the system. This entity would be responsible for assigning space on the network and designing the access and circuit for each location. This entity would also be responsible for identifying communication needs and making arrangements to provide connections or additions to the network.

6.4.2 Leased System

A second strategy is to lease a state-wide communication system from the telephone company. The WSDOT MIS has an existing leased line network in place. This strategy would entail expanding the capacity of the network to accommodate the additional needs of the ITS applications. This type of network would consist of a combination of dial-up, leased and high bandwidth lines. Dial-up lines would be used in remote areas or for devices that have a small quantity of data. Leased lines would be used for field elements that need to be continuously connected to a Traffic Management Center or WSDOT office. High bandwidth lines would be used for video or for administrative networks with high bandwidth requirements for transmission of data, volume and speeds.

Listed below are some of the advantages and disadvantages to using a leased system.

Advantages

- The advantages would include a potential reduction in construction costs. In many of the locations where WSDOT has communication needs, telephone companies already have service so that leased facilities would only have to be extended from existing facilities.

- A second advantage would be that the phone company would be responsible for scheduling and performing system operation and maintenance.
- The system would be somewhat flexible. Additional lines for voice or data could be readily added to most locations with telephone company facilities.

Disadvantages

- Additional lines with a high bandwidth may not be available in areas where they are required.
- The state would be subject to the scheduling and implementation priorities of the telephone company.
- Emergency repairs would be performed according to priorities set by the telephone company.
- The network would be subject to monthly lease charges. The charges could be changed by the phone company with little or no notice.
- The network may be impacted by the volume of data and the number of other users served by the telephone company. In areas of high usage, devices on dial-up lines may not be able to obtain access to the dial-up network. The high bandwidth services may be slowed down by a high volume of data being transmitted by other customers.

6.4.3 Combination System

A third strategy is implementation of a combination of the methods discussed above. This strategy would determine the best technology for each service, corridor or WSDOT user. The communication link would then be designed using this technology to combine the device into the network.

This type of system would give the state the most flexibility for operation and growth of the network. For example in situation where there is a stretch of roadway that has one VMS installed on it, the best choice for this application may be to use a dial-up line from the phone company. A few years later two or three more devices are added. It is decided that a leased dedicated line would provide better service. The dial-up line is replaced. A few years later a large number of devices, including a couple of video cameras are added to the roadway. At that time it is determined that an optical fiber system through the area would be the most economical communication alternative. The fiber is designed for the roadway and the telephone line is disconnected. A second example of a combination network would be to use the existing MIS leased line network for an ITS application now. In a few years when data needs exceed the capacity of the leased line , a fiber optic line or a digital radio solution would be installed.

6.5 RECOMMENDATIONS

This section will evaluate the strategies based on the following qualitative measures:

Flexibility - The strategy will be rated on its ability to be flexible to changing conditions including environment, usage and system growth.

Reliability - The strategy will be rated on its perceived reliability. This would include susceptibility to the environment, and downtime due to anticipated system repairs.

Capacity - The strategy will be rated on its perceived ability to handle system capacities including large bandwidth services. Also considered will be the ability to add capacity as required by changes in usage.

Quality - The strategy will be rated on its system quality. This will include susceptibility to system noise caused by magnetic interference as well as interference caused by other factors.

Financial - The strategy will be rated on a qualitative measure of system costs. This will be determined on perceived costs for design, installation, maintenance and operation.

	State Owned	Leased	Combination
Flexibility	2	2	2
Reliability	1	0	1
Quality	1	1	1
Capacity	2	1	2
Financial	-1	-2	1
TOTAL	4	2	7

Table 6.1 Evaluation of Strategies

The strategies were evaluated in the table based on their ability to provide the characteristic desired as well as the ability of the state to control the characteristic being considered.

Based on the table above the recommended strategy is to use a combination of technologies to build the most desirable network. This system would be the most flexible as well as the most cost effective. A communication system based on a combination of technologies would allow WSDOT to provide the best communication medium for each communication link. WSDOT would evaluate the costs, quality and capacity required for each link and decide on the best solution rather than use one solution for all situations.

SECTION 7 - RECOMMENDED CORRIDOR STRATEGIES

This section addresses the recommended corridor communication strategies for a state-wide communication network.

7.1 ESTABLISHING CORRIDOR COMMUNICATIONS REQUIREMENTS

When developing criteria for communication system recommendations, capital costs of system implementation as well as the ability of each alternative to accommodate a phased system implementation will be considered.

The backbone communication system requirements include:

- Compatibility with ITS devices
  The protocol and configuration of the network must be compatible with the ITS devices installed in the corridor.
- Easy access to network users
  The network alternative selected should have access points that are easily accessible for connection to ITS devices, agency or WSDOT offices as well as Traffic Operations Centers.
- Economical to install
  The cost of installing the selected network alternative including design, permitting, and construction must be low.
- Highly reliable
  The network alternative selected must be highly reliable with a minimum of disruptions in service due to poor transmission quality or equipment failure.
- Capacity for current and future uses
  The selected network alternative should have high bandwidth to include future increase in data and video transmission.

- Alternative routing available

  The network alternative must have the ability to develop alternate routing for the communication path in case of emergency or path failure.

- Broadcast capabilities

  The selected alternative should have the ability to take a signal from one source and broadcast it simultaneously to multiple destinations.

- Conform to industry standards

  The network that is installed must conform to industry standards for communication construction and operation.

- Support multiple types of network interfaces

  The network alternative should have the ability to interface with a variety of devices and protocols.

- Constructable in segments

  The alternative network selected must be constructable in segments due to the character of funding availability. A constructed segment should be operational without requiring immediate construction of the entire system.

- Easily expandable

  The alternative selected should protect the State's capital investment by easily accommodating the addition of future data and video channels to the system without replacement of major equipment components or disruption of existing service. Similarly, the system should easily accommodate the modification of network topology by the addition of tributary communication routes to other geographical areas or intersecting highways.

- Economical to maintain

  The network alternative selected must be economical to maintain including equipment repair and preventive maintenance.

7.2 COMMUNICATION NETWORK DEVELOPMENT

This report provides the foundation for a twenty year program of development for a state-wide communication system infrastructure. Two items for further study as part of the near term development program are the assessment of public/private partnerships to support the development of the communications infrastructure and development of an emergency preparedness plan.

The use of private/public partnerships can foster the evolution of new ideas, which may provide alternative methods of funding the development of the communications backbone network. The use of this type of partnership may mean that one or more telephone service providers would build a communication duct bank in the state highway right-of-way. As a condition of allowing this arrangement, the state may have use of several of the conduits in lieu of lease payments. Shared use of the microwave radio towers with a private sector partner (or partners) is another application of this approach. Either of these approaches would allow the state full use of its rights of way without having to fully fund construction of a ductbank and support structures, as well as allowing a private company to provide service through the area and maximize their profits.

Emergency preparedness would consider natural disasters as well as crisis caused by events or circumstances. Western Washington is an area well known for earthquakes. This study would consider the damage that could be caused to the backbone communications system by a large earthquake and develop recommended alternatives to keep the communication system operational. One of the methods this study would consider it is the availability of alternate routes for portions of the communication network. For example, an expanded SONET microwave radio network may act as a backup to the optical fiber SONET network. This additional study effort would also consider developing emergency procedures for notification of equipment failures, response to emergency conditions such as notification to users, as well as methods for returning the network to service. Emergency conditions can be caused by any of the following examples:

- Equipment failure
- Power failure
- Failure of telephone company connections
- Failure of environmental control equipment
- Construction accidents; i.e. dig-up
- Cable penetration by rodents
- Earthquake
- Lightening
- Fire
- Flood

7.3 STATE-WIDE COMMUNICATION PLAN

A state-wide communication plan will present several advantages for WSDOT. Among these advantages would be elimination of recurring costs for leased lines to local operations centers and regional offices and connectivity for ITS devices on the state-wide freeway system. In the near term, communication between offices will continue to use the existing T1 leased line network, which is efficient and reliable. The existing leased line network can be expanded for inter-office communication. As the capacity needs for the communication network expands past the capacity of the leased line network these facilities can be replaced with WSDOT owned facilities. A high-capacity state-wide system will also provide a high quality connection suitable for video transmission. Due to the ability to assign space on the network dynamically, the system will be particularly cost effective for administrative applications.

7.3.1 General

WSDOT has regional offices in Spokane, Yakima and Wenatchee and local offices in Mt. Vernon and Bellingham. This section will briefly discuss the provision of a communication link to the backbone network to these operational centers, thereby providing the beginning of a state-wide network. The evolution of a statewide backbone communication network will support the connection of ITS devices installed along the state freeways, in addition it would be beneficial for connection of selected devices in rural areas; in particular CMS/VMS's associated with weather stations and weigh in motion applications. Installing WSDOT-owned facilities along the interstate corridor will allow those devices to easily be connected to the communication system.

Administrative communication with the regional offices will continue to take place over the existing leased line network. ITS applications can also be run over the existing T1 lines until the capacity is depleted. At that time, WSDOT owned facilities with a higher bandwidth can be installed to continue expansion of the network. Voice and data can be run over the T1 lines to reduce costs associated with having two separate leased networks.

Expansion to the East and to the North can be accomplished by making use of the existing network of radio sites owned and operated by both the WSP and WSDOT. The microwave radio system to the East could be developed in stages to spread the costs over a period of years. Future connecting routes to the regional offices in Yakima and Wenatchee would help to reduce administrative recurring costs for leased telephone lines by providing a connection to Headquarters over the WSDOT owned network.

7.3.2 Communication Route to the East

The existing leased line network consists of a T1 line to the South Central Regional office in Yakima and from there T1 lines to the North Central and Eastern Regional Offices. These lines can be used for voice and data until they reach capacity. The T1 line from Olympia to Yakima is projected to reach capacity in the near term as it is carrying voice and data to three regional offices. The lines to Spokane should reach capacity at the beginning of the mid-term and the T1 line to Wenatchee (North Central Region) will reach capacity in the mid to late term. At that time, alternatives need to be considered to expand the capacity of the communication network. One alternative is to lease a second T1 line. The recommended alternative is to install a WSDOT-owned high bandwidth facility to accommodate voice, data and video applications.

The recommended route to the East would use existing WSP and WSDOT microwave radio paths to establish a backbone SONET communication route to Spokane. Figure 7-2 shows the proposed route to Spokane as well as the future spur routes to Wenatchee and Yakima. The route would begin with a radio path from the Northwest Region office to Squak Mountain. The path would continue East passing through sites at Grass Mt. and Stampede Pass to reach Vantage. The path at Vantage would continue east to sites at Beverly, Monument Hill, Creston Butte, Mt. Spokane, and into Spokane. The mainline communication route would be accomplished using SONET microwave equipment with a transmission capacity of OC-3.

A spur to the south from the site at Vantage following Highway 82 would provide a communication link to Yakima and the South Central Region Office. A spur to the west from Monument Hill to Burch Mt. and into Wenatchee would provide a link to the North Central Regional office. These spurs would use SONET microwave with a capacity of OC-1.

All sites referred to are existing facilities that, with a few exceptions, are believed to require few modifications to accommodate the addition of SONET microwave equipment at the site. The exceptions are Grass Mt., Stampede Pass, Beverly and Creston Butte.

7.3.3 Communication Route to the North

The existing communication network consists of a T1 link from Olympia to the Northwest Regional Office and from there to the various Project Engineers' offices. These lines would continue to be used until they reach capacity at which time WSDOT-owned high bandwidth facilities would be considered. The T1 line to the Northwest Region office from Olympia should reach capacity in the near term. T1 facilities to the Project Engineers offices will probably not reach capacity until the late term unless they are used to transmit ITS applications. In particular, ITS applications between Bellingham and the Canadian border can be brought back to the Bellingham Project Engineers office and put on the Wide Area Network to the Northwest Region office. This could cause the T1 to reach capacity early in the mid-term.

The communication route to the North will provide a communication network along I-5 from Seattle to Bellingham for connection to ITS devices as well as providing a connection from the Northwest Regional office to the local WSDOT offices in Bellingham, Mt. Vernon and Everett. Figure 6-3 shows the proposed route from the Northwest Regional Office to Bellingham. Due to population and traffic densities the route to the north would not require the same capacity as through the Seattle-Tacoma area. An OC-12 to Everett and OC-3 to Bellingham should adequately handle the capacity for 10-15 years. The 20 year plan would consider upgrading the capacity of both routes. The OC-12 to Everett may need to go to OC-48 and the OC-3 to Bellingham would go to OC-12.

The current design for the SONET optical fiber system being implemented in the Northwest Region has proposed hubs situated in Everett and in Marysville. A lateral optical fiber connection to the Everett hub from the local Everett WSDOT office would provide a link to the communication system. A section of the communication network from 164th to Broadway has an advertising date scheduled for September 1996 however further design and construction to the north has not been scheduled.

The optical fiber mainline would continue from the proposed Marysville hub in the I-5 right of way to the local WSDOT office in Mt. Vernon. An optical fiber or wireless connection from the Mt. Vernon WSDOT office to the WSP microwave radio site in Mt. Vernon where the main communication backbone will go from optical fiber to SONET microwave radio to continue north. The SONET microwave radio system would pass through existing sites at Little Mt., Galbraith, and Bellingham. The local WSDOT office in Bellingham would be connected to the communication network by means of optical fiber, or wireless communications.

The existing SONET network in the Seattle area has been designed so that every hub can be served from two directions. This provides a very secure system. The TSMC at Dayton Avenue is connected to the optical fiber mainline with a single fiber route between the office and I-5. This compromises the benefits of having the ring network by making the system vulnerable at this one link. If this link goes down all communication between the hubs and the TSMC is lost. It is recommended that a second fiber route be installed to the SONET network. Ideally it should intercept the network at a different hub than is being used for the existing connection.

SECTION 8 - PRIORITIZED CORRIDORS FOR FURTHER STUDY

This section will examine the corridors identified in Section 1 and determine how they should be prioritized. Each corridor will be described and evaluated against a set of criteria and prioritized for the recommended order of study.

I-5, Seattle to the Canadian Border - This corridor passes through an urban area north from Seattle to the Everett-Marysville area. The roadway from Marysville to Bellingham, is somewhat rural in nature. Between the Canadian border and Bellingham it is predominately urban however there are still some rural areas. This corridor is very highly traveled by commercial trucking as well as travel for recreation, tourism and inter-city commuting. Technical memorandum #5 recommended the optical fiber system be extended as far north as Marysville, as called for in the current Northwest Region communications plan. A digital microwave radio system would be used from Marysville to Bellingham where an optical fiber would be installed to communicate locally. The optical fiber could be extended on to the Canadian border or a digital microwave radio link could be established. The choice would be made based on an evaluation of communication needs for the rural area between Bellingham and the border.

I-90, Seattle to Spokane - This corridor is urban east from Seattle to North Bend, on the west side of the Cascade Mountain Range. From North Bend to Spokane, I-90 passes through a rural area. There are several large towns, the largest of which is Ellensburg, located approximately in the center of the state. As I-90 approaches and goes through the Spokane area, it is again urban. Technical memorandum #5 recommends a digital microwave radio system for the majority of the link to the east. An optical fiber would be installed in the urban area around Seattle as well as in the urban area around Spokane to handle communication with field devices.

Highway 2, Everett to Spokane -This corridor is predominately rural and scenic freeway areas. The freeway generally encounters heavy snow falls each winter in the mountain pass, Stevens Pass. The road is one of the two major east-west routes across the Cascade mountains. The corridor is heavily traveled by commercial and recreational traffic. There also may be quite a bit of traffic for inter-city commuting. Communication needs for this freeway corridor will include high bandwidth data and video connections in the near term or early in the mid-term.

Highway 82, Ellensburg to the Tri-Cities -This corridor is predominantly rural. The majority of the traffic is commercial trucking, and inter-city commuting. On one or two occasions throughout the year this highway will be heavily used for recreational travel. The future needs for communication for ITS or for traffic control along the highway will be small until the mid to late term. The South Central Regional Office is in Yakima, which is located near the centerpoint of the highway. The communication needs for the office will grow as the use of WSDOT communication facilities for internal administrative communications is adopted. Currently communication with the regional office is served by a leased T1 from the telephone company. This existing line should serve the inter-office communication requirements until sometime late in the mid-term.

Highway 101, along the Pacific Coast - This highway is used primarily for recreational uses. There is some commercial trucking traffic, and some commercial traffic related to the fishing industry however the majority of the traffic is recreational and seasonal. Winter traffic volumes are relatively low. Communication needs to support ITS applications for this section of roadway will be minimal and may not be required until the late term. The area may best be served by dial-up telephone lines. There would be little or no requirement for administrative communications along this route.

Highway 410, Tacoma to Yakima -Parts of this highway are closed in the winter due to high snow accumulation. The need for communications along this highway would be to support ITS applications associated with the highway closures and other weather conditions. Through the Pass areas notification of incidents may also be desired. Yakima is the regional office so communications along this roadway will provide a path to the Olympia Service

Center if a back up route is required. The traffic volumes along this highway are not perceived to be high.

Highway 14, Vancouver to the Tri-cities -This highway is traveled for recreation and tourism in the Dalles area between Washington and Oregon. It is also used for commercial, commuting and recreational traffic to the Tri-city area: Pasco, Richland, and Kennewick. The Tri-city area is the home of the Hanford Nuclear Reservation that will account for some commercial truck traffic. Communication needs for Highway 14 are anticipated to be light for the near term, picking up slightly toward the end of the mid-term.

Highway 395, Tri-cities to Ritzville -This corridor will be primarily for commercial truck traffic with some inter-city commuting. Highway 395 coincides with I-90 between Ritzville and Spokane. The section of highway 395 south of Ritzville traverses an area that is very rural. There will be very minimal communication needs through this area.

Highway 20, Anacortes to Spokane -This cross-mountain route is primarily through rural and scenic areas. The corridor is closed 4 or 5 months out of the year due to heavy snow falls. The route is seldom heavily traveled. In the summer months traffic volumes increase due to recreational and tourist traffic. Some commercial traffic will go over this pass particularly if their destination is in Canada or in Northeast Washington. The communication needs for WSDOT administration in this corridor are minimal. Communication to support ITS applications through the Pass Area are projected for the mid-term.

Each of the corridors will be evaluated against the qualitative criteria listed below to prioritize them for future study. All corridors will require further study to determine ITS applications, implementation schedules and actual communication needs.

Traffic Volumes - Traffic volumes referred to here are a perception only. Traffic counts need to be taken to verify the actual occupation of the corridor.

Safety Considerations - This will take into consideration the perceived problem areas along the roadway. This could be dangerous areas due to rock slides or weather conditions.

Communication Needs - This is the perceived need for an extensive communication network through the corridor. It will be based on the level of complexity of choices for drivers as well as the variety of vehicles anticipated to travel through the corridor.

Effect of WSDOT Administrative Requirements - This will take into consideration the proximity of WSDOT Regional or Project Offices and will consider if the corridor will be used as a route for administrative communications.

Corridor	Traffic Volumes	Safety	Comm. Needs	WSDOT Admin. Req.	TOTAL
I-5	2	1	2	1	6
I-90	2	2	1	2	7
I-2	1	2	1	0	4
SR 82	1	0	1	1	3
SR 101	0	1	0	0	1
SR 410	1	1	0	0	2
SR 14	0	1	0	0	1
SR 395	1	0	0	1	2
SR 20	1	1	1	0	3

Table 8.1 Corridor Prioritized for Future Study

The nine corridors identified by this report can be prioritized based on the totals shown in the above table. This table shows that I-5 and I-90 are the highest priority of the corridors for study. The second major cross-mountain pass, SR 2 or Stevens Pass, is the next highest priority. The corridors used primarily for recreation, SR 101 and SR 14, are the lowest priorities.

SECTION 9 - SUMMARY OF RECOMMENDATIONS

This section will provide a summary of the recommendations made throughout this report.

9.1 STRATEGIES

The strategy recommended in Section 4 is to use a combination of technologies to build a network that is the most cost effective and flexible. Selecting the technology to be used on an individual basis allow the state to consider the bandwidth requirements and the facilities available in the vicinity. The state would be able to take advantage of WSP microwave sites for shared facilities as well as existing facilities for other agencies. The best medium for the application would be chosen.

9.2 RECOMMENDATIONS

The study recognized that the communication network must meet certain criteria to meet the needs of WSDOT and other state agencies. Chief among these needs are system reliability and quality. To develop a communication network, financial considerations for owning and/or operating the system must also be taken into account. Considering these things the report makes the recommendations listed below.

- Install a redundant communication path from the existing SONET network to the TSMC.

- Combine voice and data applications on the existing leased T1 network. This will eliminate leased charges for a second communication network, which serves only the PBX at selected offices.

- Continue to use the existing T1 leased line network for interoffice communication. Use the network for ITS applications where it makes sense.

- As capacity is depleted on the T1 network replace the links with higher bandwidth leased line, optical fiber or microwave radio connections.

- This report recommends that a combination optical fiber and digital microwave system be planned for the ultimate system configuration. Optical fiber will be used for urban corridors and digital microwave radio for rural areas.

9.3 CORRIDORS FOR FURTHER STUDY

Section 8 discussed various corridors in the state and prioritized them for future study. Listed below are the corridors in the order recommended for further study.

I-90 - Seattle to Spokane
I-5 - Seattle to the Canadian border
SR 2 - Everett to Spokane
SR 20 - Anacortes to Spokane
SR 82 - Ellensburg to the Tri-Cities
SR 410 - Tacoma to Yakima
SR 395 - Tri-cities to Ritzville
SR 14 - Vancouver to the Tri-cities
SR 101 - Pacific Coast

APPENDIX A
CURRENT COMMUNICATION TECHNOLOGY AND FUTURE TRENDS

A.1. COMMUNICATION SYSTEM TECHNOLOGY

In general, three types of information are transmitted over an ITS Traffic Management System communications network; voice, data and video. These communication transmission requirements fall into four transmission bandwidth categories. They are voice grade, narrow band, wideband, and broadband. The purpose of this appendix is to provide Washington State transportation planning officials and others responsible for the financial aspects of transportation planning some level of understanding of the communications technology associated with ITS systems so they may be capable of making an independent judgment on the proper course of action for WSDOT or, as a minimum, to a better understanding of the rationale for a specified technical course of action and the benefits to be derived from this action. The communication transmission required to support voice, data and video communication services is briefly discussed below.

A.1.1. Voice Communications

Traffic control system voice communications are generally used in support of maintenance operations. These communications traditionally have been either through telephone services at a control device location or via state-owned or leased mobile radio service. Voice communication services are normally transmitted at 300 Hz to 3.4 kHz analog or 56 kb/s digital.

A.1.2. Data Communications

Traffic control system data communications have traditionally been low-speed, narrow band (i.e., 1200 b/s) using relatively inexpensive special purpose communications and control interface devices. However, data communication transmission speed requirements for ITS Traffic Management Systems are approaching 9.6 kb/s (still narrow band) and will likely approach 10 Mb/s (wideband) within a decade.

A.1.3. Video Communications

Traffic control system applications for video service are primarily in the area of video surveillance systems at this time. It is quite feasible that on-site video services may likely emerge for incident management programs; especially as it relates to hazardous materials fires and cleanup. The three notable video transmission methods are "slow scan", "real time" full motion, and "real time" compressed. Video signals can be transmitted over a number of media such as coaxial copper and optical fiber cable, terrestrial and satellite microwave radio, and infrared free space transmission. In general, real-time, color video images from CCTV cameras place the heaviest load on a communications network. Full-motion video requires a broadband service channel with 4.5 MHz of bandwidth per camera for analog transmission or 45 Mb/s per camera for digital transmission, as compared to an analog bandwidth requirement of only 0.4 MHz for each 1.2 kb/s data channel. Additionally, native video is an analog source while native data communication is digital. In essence, the video bandwidth requirement is the controlling factor in analyzing and designing a communications network.

Camera Control operation (pan, tilt, zoom, focus, and the identification function) for video surveillance (CCTV) cameras is a data communications transmission and the communication support parameters for this function are similar to the general requirements for data communication transmission as previously stated.

A.2. Communications Distribution

A major communications network topology associated with an ITS traffic management system generally consists of two principal forms of transmission or connectivity. One is the trunk or "mainline" system and the second is the local distribution system.

The transmission of both data, voice, and full-motion, color video over a State-owned network will require a broadband transmission medium; or, a combination of both narrowband and broadband transmission mediums in both of these topological areas of transmission. The optimal transmission medium is an optical fiber cable inasmuch as it can support the transmission capacity requirements of both the mainline and local distribution. However, in the instance of the Seattle-Portland corridor, this may not be the optimal economic solution. Therefore, other mediums such as the use of copper cable and digital microwave radio are included as candidate transmission mediums. The general transmission characteristics of optical fiber as a communications medium is large capacity and noise immunity. The general characteristics of digital microwave radio as a communications medium are - moderate capacity and low ambient noise. It requires a clear line of sight transmission path.

Both fiber and microwave radio are by nature point-to-point technologies. That is, a single origination point and a single destination are required for any given link. Point-to-multipoint configurations are not really feasible. Consequently, a State-owned microwave radio or optical fiber cable configuration for data communications transmission must use a centralized distribution arrangement.

A.3. Multiplexing

Currently, the dominant multiplexing schemes in use in communications transmission are frequency division multiplexing (FDM), which is an analog based technology, and time division multiplexing (TDM), which is a digital based technology.

Several low-speed (or wideband) data channels can be time division multiplexed (combined together) into a high-speed data channel, and transmitted over a broadband system from the Traffic Systems Management Center (TSMC) to a communications node or distribution point. At the communications node location, the combined signals are demultiplexed (split) again into low-speed (or wideband) data channels and then transmitted to the field devices. The media to access field devices may be either twisted-pair or coaxial copper cable, or optical fiber cable. Similarly, the responses from the field hardware are gathered at the communications node, multiplexed, and transmitted back to the TSMC where they are demultiplexed and read by the computer or sent to a video monitor.

FDM is popular as the transmission methodology for cable television networks because it is a relatively simple technology and easy to implement. It is widely used in closed circuit television networks that do not have a large number of channels and the transmission distance is not overly long - under 30 miles. This transmission method is a mature technology that offers a relatively inexpensive means to support video communications.

TDM can also be utilized for video transmission applications over a digital transmission system, but the cost of digitizing the analog video signal and transmitting it over digital transmission facilities can be costly, especially if a full NTSC, 30 frames per second quality signal is required. Currently, this quality of signal performance can only be provided by codecs that function at the DS3 (45 Mb/s) rate.

Transmission of video images over optical fiber cables presents a problem, especially for a communications hub arrangement. Typically, to avoid multiplexing, a separate fiber must be dedicated to each camera. Given that multiple-fiber cables are small and economical, and the fact that a single-mode optical fiber utilizing frequency division multiplex equipment can support a single analog video signal up to 15 miles without the use of regenerative repeaters, this solution is very attractive for the video communications between the cameras and each communications node location. This same approach can be utilized for digital microwave transmission from a camera site so long as a clear line of site path exits between a camera site and a communications hub point.

At the communications node location there are essentially two choices in network design for video transmission between the node and a TSMC. These two choices are AM/FM multiplexing techniques, which can be used to transmit multiple video images over a dedicated optical fiber from a communications node, or digitizing the analog video signal and presenting it to a universal broadband digital system such as synchronous optical network (SONET) equipment. It is worth noting that there is a proprietary frequency division multiplex system that will support up to 16 video channels simultaneously over one single mode fiber for distances up to 30 miles. Unfortunately, the multiplexing technique of this equipment is not compatible with the digital data transmission of a SONET system; thereby necessitating separation of the functions onto different fibers. It is practical to use a common bundle of single mode fibers, and to dedicate one or more fibers per communications node exclusively for video transmission and the other single mode fibers for SONET applications. It is also important to note that SONET microwave radio is available which could be used to develop a SONET network in the Seattle-Portland corridor.

A.4. DISTRIBUTION MEDIA CONSIDERATIONS

Local distribution of communication service may be supported by either wireline or wireless transmission media. It is implicit that communication with vehicles will be conducted via wireless communications. Communication with traffic devices or other ITS service devices may be supported by either wireline or wireless technology or perhaps a combination of the two.

A.4.1. Cables

The local distribution communication system for a traffic management system is that portion of the system that connects the field devices to the equipment of the mainline system.

Because the short haul (7 miles or less) distribution portion of the network topology carries a smaller amount of information than the long haul (mainline) portion, different types of cables or wireless technology may be utilized. This subsection provides a description of a currently popular method of local distribution connectivity for traffic management systems.

The voice and data field devices can be served via twisted-pair copper telephone cable, and the video cameras can be served with either coaxial copper cable or optical fiber cable from a local distribution point depending upon a particular design and the distances involved. Since the pan/tilt/zoom functions for the cameras are controlled via a data circuit, the pan/tilt/zoom controllers at camera locations can be served with twisted-pair copper circuits.

Depending upon a discrete design, copper twisted pair cable is routed away from an equipment cabinet in as many directions as there are traffic management system devices. The twisted-pair cable will contain the number of pairs required to support the quantity of devices planned for a roadway section plus spares for future expansion. In general, a 25 to 50-pair twisted pair cable is the norm.

Circuits to data devices such as ramp metering controllers, traffic count stations, and camera controllers are configured by connecting the lateral cables for like devices to the same pairs in the main distribution cable. This is called a "multidrop" configuration since the service for the various devices are "dropped" from the same cable pair. No voice circuits are required for field equipment locations because it is assumed that maintenance staff will use either commercial cellular telephones or a state owned UHF mobile radio service for communication.

A.4.2. Optical Fiber Cable Technology

Communications utilizing a light source as a signal carrier and optical fibers as a transmission medium are termed "optical fiber communications". In an optical fiber communication system, voice, video, or data communications are converted from an electrical signal to a coded pulse stream of light using a suitable light source. This pulse stream is carried by optical fibers to a regenerating or receiving station. At the final receiving station the light pulses are converted to electric signals, decoded, and converted into the form of the original information. Currently, optical fiber communications are regularly used for voice, data, and video communications.

The concept of optical fiber communication is a simple one. Transmission is performed using a tubular glass fiber rather than a metallic conductor. The transmission of intelligent signals is performed by means of light impulses that are transmitted into a glass fiber structure ("waveguide" or "lightguide") that confines and guides a beam of light between points of origin and destination. Optical fiber transmission principles are complex, involving light wavelength, phasing, refraction, reflection, and dispersion within the light distribution medium; light signal attenuation through the medium; and other critical factors. Designing an optical fiber network entails substantial engineering planning effort.

Nevertheless, the benefits of optical fiber transmission are significant for long haul communications applications. Some of the elements that differentiate optical fiber transmission from metal transmission media are:

- A pair of optical fibers can support many more circuits than a metallic path,
- Immunity from electromagnetic interference (EMI), radio-frequency interference (RFI), and electromagnetic pulse damage (EMP),
- High communications security integrity for data transmission,
- Use of small cable diameters and low-weight cable, and
- Safety in hazardous environments.

A.4.3. Classification of Optical Fibers and Attractive Features

Fibers used for optical communication are waveguides made of a transparent dielectric whose function is to guide light over long distances. An optical fiber consists of an inner cylinder of glass, called the "core", surrounded by a cylindrical shell of glass of lower refractive index, called the "cladding". Optical fibers may be classified in terms of the refractive index profile of the core and whether one mode (single-mode fiber) or many modes (multimode fiber) are propagating in the guide.

In general, when a transmission medium must have a very high bandwidth, a single mode fiber is used. For intermediate system bandwidth requirements between 200 MHz and 2 GHz, such as is found in traffic control networks or in local area networks a single-mode fiber is generally chosen. Single-mode fiber offers significantly less attenuation and higher capacity capabilities than multimode fiber, and for this reason, the single-mode fiber tends to be used for long distance communications. For applications such as short data links where lower bandwidth requirements are placed on the transmission medium, either a graded-index or a step-index multimode fiber may be used although many users are installing single mode fiber for this application to provide future flexibility. The original engineering study conducted for the SC&DI system in the Northwest Region recommended substantial use of multimode optical fiber cable. A decision has been made by the Region to install only single-mode cable due to its inherently better transmission characteristics.

Because of their low loss and wide bandwidth capabilities, optical fibers are supplanting twisted-pair wire or coaxial cables as the long haul transmission medium in broadband communication systems. The small size, small bending radius, and light weight of optical fiber cable is very important where space is at a premium, such as in crowded ducts under a city street. Because optical fibers are dielectric waveguides, they avoid many problems such as radiated electromagnetic interference, ground loops, and, when installed in a cable without metal, lightning-induced damage that may effect other transmission media.

Optical fiber transmission is immune to electromagnetic interference (EMI) and is not affected by electrical signals or power surges. An optical fiber cable is especially suited for installation in an environment that is subject to lightening ground strikes. Therefore, fiber can be used in electrically noisy environments or power surge areas such as those found in an outside plant installation along a freeway. Data transmission error rates are extremely low when using fiber transmission. Bit error rates are typically on the order of one error in a billion bits ($1x10^{-9}$) of transmitted information. Optical fiber transmission emits no radiation. As a result, it is difficult to tap an optical fiber without detection of the resulting loss of signal. Therefore, it is a highly secure medium.

Using optical fibers offers a great deal of flexibility. An engineer can install an optical fiber cable and use it initially in a low-capacity (low-bit-rate) system. As the system's requirements expand, the engineer can take advantage of the broadband capabilities of optical fibers and upgrade the supporting electronics to a high-capacity (high bit rate) system by simply adding to or changing the electronic terminal equipment.

A.4.4. Optical Fiber Transmission Characteristics

The proper design and operation of an optical communication system requires a knowledge of the transmission characteristics of the optical sources, fibers, and devices used to join lengths of fibers together (connectors, couplers, and splices, etc., as well as the electronic equipment to be utilized in conjunction with the optical fiber). The transmission criteria that affect the choice of the fiber type used in a system are signal attenuation, information transmission capacity (bandwidth), source coupling, and interconnection efficiency. Interconnection efficiency is usually measured in terms of signal attenuation that is attributable to losses within the fiber plus the losses occurring in splices and connectors.

The information carrying capacity, or bandwidth, of a fiber depends on dispersion of the transmitted light. This is the phenomenon that causes light that is originally concentrated into a short pulse to spread out into a broader pulse as it travels along the length of an optical fiber. When the pulse is transmitted it may contain several different wavelengths of light. This is due to the characteristics of the optical source known as the spectral width. Each wavelength of light will travel at a slightly different speed. The net effect is that, as the spreading increases, there is a potential for interference between bits of information. If the pulse is spread enough so that the last portions of one pulse arrive after the first portions of the following pulse, then inter-symbol interference occurs and the individual pulses can no longer be distinguished from each other. Pulse dispersion occurs as a function of both pulse width (data rate) and distance. This directly impacts the bit error rate (BER) performance of the system. For this reason, the capacity of optical fiber systems is expressed in millions of bits per second per kilometer (Mb/s-km), the products of data rate and distance.

Standard single-mode fiber offers the user an efficient path for broadband transmission of voice, data, and video information at both 1330 and 1550 nanometers (nm). With the commercialization of optical amplifiers and the development of more cost effective, improved lasers, non-telephone company users are beginning to explore operation of systems in the 1550 nm wavelength region. Operation at this longer wavelength permits a decrease in the number of regenerative repeaters resulting in cost savings and an increase in system reliability. Dispersion shifted single-mode fibers exhibit an even lower attenuation at the 1550 nm wavelength, which will provide a better operational performance. This is advantageous in that it exhibits dispersion performance that is nearly six times better than that experienced at 1330 nm. While techniques exist to compensate for the increased dispersion, dispersion-shifted fiber can be deployed to avoid the requirement for such correction techniques while still capitalizing on the lower attenuation performance at the longer wavelength.

It should be noted however that from an economic perspective dispersion-shifted optical fiber is approximately 50% more expensive than standard single-mode cable. Therefore its use normally requires some offsetting equipment savings in a system design.

A.4.5. Optical Fiber Equipment

The transmitters used for optical fiber cable include both injection laser diodes (ILDs) and light emitting diodes (LEDs). The ILD provides high power and high bandwidth but are expensive. Light emitting diodes normally are used for transmission distances of less than 10 km and for data rates of 500 Mb/s or less. ILDs normally support transmission distances of 50 to 75 km and for data rates up to 2.3 Gb/s.

Optical receivers include photo diodes and photo transistors that are similar to the light meters in cameras. They are selected to match their characteristics to that of the medium and the transmitter.

The practical implementation of optical fiber communication systems requires the use of interconnection devices such as splices or connectors. The diameter of individual fibers is less than that of a human hair, yet splicing requires nearly perfect alignment of two fibers so that light can be transmitted between them with minimal attenuation or reflections. Automated equipment is available to simplify this process. A connector, by definition, is a removable device used where it is necessary or convenient to easily disconnect and reconnect fibers. A splice, on the other hand, is employed to permanently join lengths of fiber together. The losses introduced by splices and connectors are the single most important consideration in the design of an optical fiber system because they can be responsible for a significant percentage of the attenuation in a multi-kilometer communication link.

A.4.6. Microwave Radio Systems

An alternative transmission medium for the mainline system is a microwave radio relay system. The cable transmission media described above differ from microwave radio in that they provide a predictable transmission path with relatively controlled characteristics. Radio, less expensive to construct than a cable based system, requires a solid engineering investment in the calculation of the probable behavior of the path and selection of modulation and signal-processing techniques that will overcome the unpredictable characteristics of the medium. The characteristics of the path are significantly affected by the transmission frequencies of the system.

Microwave systems are essentially radio systems that operate at very high frequencies. Above two billion hertz, microwave has a "line-of-sight" transmission characteristic and offers systems a high communication channel capacity. Radio waves in line-of-sight systems travel in virtually a straight line. They are limited by the horizon (curvature of the earth) and geographic topology of the selected path. Microwave energy can be focused into a narrow, strongly directional beam, similar to a beam of light. Antenna towers must, therefore, be rigid enough to withstand high winds without excessive antenna deflection, which can result in increased path attenuation.

Most civil government and industrial microwave radio systems operate in the 6, 11, 18, and 23 GHz bands. The spacing between microwave repeater stations is determined by the geographical topology of a given radio route; the technology used in the terminal equipment; and the transmitter power permitted by the Federal Communications Commission (FCC). Typical repeater spacing in the 6 GHz spectrum are 20 to 25 miles, and 5 to 10 miles in the 23 GHz spectrum. Longer spacing is possible using larger parabolic antennas and when the effects of signal fading caused by precipitation are expected to be minimal. Because microwave communication path design can be controlled, the same frequencies can be reused relatively frequently between microwave radio station locations, with the result that the identification of available frequencies is simplified.

In long microwave paths the strength of the transmitted signal is subject to fading. At microwave frequencies this can be caused by a variety of effects including atmospheric changes or ground and water reflections in the propagation path. When using frequencies above 10 GHz, rainfall attenuation must be taken into account. For example, heavy ground fog or very cold air over warm terrain (such as thunder storms) can cause enough atmospheric refraction to reduce the power of the signal below a usable level. Fading due to weather can affect a wide band of frequencies and may last several hours. The remedy is to change antenna height or to position sites closer together.

A second type of fading, called "multipath fading," occurs at night and at dawn during the summer, when there is no wind to break up atmospheric layers. Normally, microwave energy radiated outside the line-of-sight path (called "off-axis energy") is bent by atmospheric refraction into the receiving antenna. This energy travels a longer path than the line-of-sight signal and, therefore, has a longer travel time. Depending on the amount of off-axis energy and its phase (the amount of delay relative to the primary signal), instantaneous reduction and even cancellation of the primary signal may occur. Multipath fading may recur frequently but lasts only a few seconds and is generally, restricted to a limited frequency range. It can be minimized by using "frequency diversity." Space diversity is used when significant energy is diverted consistently from the line of sight path. A second antenna is positioned to receive this energy. Because frequency diversity requires more use of the already limited radio-frequency spectrum, it is generally not applied to low-density routes. An alternative approach, "space diversity," is used in this case for paths that experience severe fading which is the use of a second frequency as a back-up route.

Between WSDOT and the WSP, the state currently has a rather extensive microwave radio system in place. Moreover, the state already has a trained work force in this technology. Hence, it is worthwhile to consider this medium as a viable alternative transmission method to support ITS requirements in the Seattle-Portland corridor.

A.5 TRANSMISSION SYSTEM TECHNOLOGY CONSIDERATIONS

A.5.1. Analog to Digital Signals

Most modern telecommunications transmission systems are predicated upon digital transmission. A detailed discussion of this subject is outside the scope of this report. However, it is important for the reader to understand certain fundamentals of this technology.

Most communications originate as an analog signal. In order to convert an analog signal to a digital signal, the signal is passed through a device referred to as a coder and to restore the digital signal to a usable analog signal it is passed through a second device referred to as a decoder. A coder and decoder can be manufactured as an integrated unit and are generally referred to as a codec (coder/decoder).

Depending upon the frequency of the original analog signal, a codec produces a digital signal of varying digital bit rates. For example, an analog voice signal which normally ranges between 300 hertz (Hz) and 3400 Hz, when encoded in the standard North American telephone communications pulse code modulation format, requires a digital stream of 56 kb/s. However, an analog video signal of commercial broadcast quality is approximately 4.5 MHz and requires a digital stream of 201 Mb/s - although signal compression techniques have reduced this to 45 Mb/s for near studio quality and 1.544 Mb/s for an acceptable high quality presentation. Because video is so significant in the communication system design requirements for traffic control system applications, video digital compression techniques are more fully explored in the following paragraphs.

A.5.2. Compressed Digital Video

The analog video signal most widely used in the United States is the NTSC signal, with a bandwidth of 4.2 MHz. Following the Nyquist theorem, an NTSC signal requires sampling at a frequency of 8.4 MHz, and with eight bits per sample, this leads to a bit rate of 67.2 Mb/s. Multiplying by three for the three color components (red, green, and blue) yields a bit rate of 201 Mb/s.

Digitizing a video signal enhances its clarity and quality, eliminating any "ghosting" (reflections), "snow " (noise) or other distortion that often affects analog video. Compressing that same signal into a much narrower bandwidth dramatically reduces the cost of transmitting it. The amount of compression can be significant - by a factor of 60 to 1 for high-bandwidth video at 1.544 Mb/s.

The process begins with a codec (short for coder-decoder) sampling the analog signal from a video camera to produce a digital display format made up of thousands of picture elements known as pixels. Once the picture has been digitized, video frames are divided into more manageable "macro blocks", consisting of 16 by 16 pixels of luminance, or brightness, and 8 by 8 pixels for each of two channels of chrominance, or color. These blocks are then analyzed by the codec to determine which picture data should be sent.

Because every pixel requires eight bits of data for transmission, a number of sophisticated coding techniques have been devised to avoid sending parts of the picture that haven't changed. Interframe coding is used to transmit relatively small differences occurring from one frame to the next. Intraframe coding is employed for major scene changes, where the sending codec instructs the receiving codec to replace all previous data with the new data being sent.

When coding is complete, a sophisticated mathematical transformation called Discrete Cosine Transform (DCT) is used to reorganize the pixel information into a more compact form and generate a series of numbers that represents pixel values. These numbers are then divided by a mathematical coefficient that makes them easier to send. Finally, the codec encodes and sends the data to the receiving site, where the information is decoded by a similar codec performing the process in reverse.

A.5.3. Standards

In late 1990, the Consultative Committee on International Telephone and Telegraph (CCITT) began ratifying a series of worldwide standards that both moves the world closer to truly universal videoconferencing, and lays the foundation for standardizing a number of CDV applications as well. The initial standards from the CCITT established guidelines for picture quality, communication and other technical requirements for high- and low-bandwidth videoconferencing, and audio standards for high-bandwidth videoconferencing only. The CCITT's work acts as a starting point for groups addressing other segments of the CDV marketplace. These include the Joint Photographic Experts Group (JPEG) for still photos, graphics and x-rays, and the Motion Picture Experts Group (MPEG) for multimedia and broadcast applications. The common denominator among the various proposed and implemented standards for picture quality is that all of them are based on the Discrete Cosine Transform (DCT). DCT technology was chosen as the backbone of the new video standards because it offers acceptable picture quality across a broad spectrum of bandwidths - from the U.S. starting point for videoconferencing of 56 Kbps to the European T1 rate of 2.048 Mbps.

The capacity of a digital compression system is measured by its rate in bits per second. An efficient compressed digital video system consumes the minimum rate possible commensurate with its quality objectives. For the most part, a compressed digital video system can be considered separately from the communication system that will be used to deliver the bit stream. Consequently, a compression system should usually be specified in terms of its required rate in bits per second.

A.6. Digital Transmission Rates

The North American Standard for the Synchronous Digital Hierarchy (SDH) for digital communication transmission is developed around ascending levels of bit rates. The fundamental rate is named DS0 (Digital Signal Zero) which functions at a rate of 64 kilobits per second (kb/s){clear channel operation}. This is multiplexed into a signal containing twenty-four (24) DS0 signals and is referred to as DS 1 (Digital Signal One). It should be noted that a DS0 channel can support one voice communication path, a data communication path of 56 kb/s (plus an 8 kb/s overhead control channel), or, in the instance of data communications, can be subdivided into multiple lower speed signals. From the DS1 level, the North American Standard provides for additional multiplexing of signals such that the concatenated signals rate becomes a DS2 at 6.312 million bits per second (Mb/s) and the DS3 rate becomes 44.736 Mb/s.

A DS3 rate, approximately 45 Mb/s, contains 28 of the basic DS1 signals, or a digital equivalent of 672 DS0 channels.

In concert with the North American Digital Hierarchy, older digital communications carrier systems and their protocols are still supported; such as “T” carrier systems. These systems are used to provide communications transmission over copper twisted pair facilities.

Framing in the T1 environment is used primarily for signaling and maintenance. Signaling is needed to set up, maintain, and tear down connections in the public network. There are mainly two types of framing. D4 framing which consists of an “in-band” signaling technique that involves using designated bit slots within the user channels to convey signaling information; or Extended Superframe Format (ESF) which offers both in-band and out-of-band signaling. Unlike D4 framing, which only offers out-of-service maintenance, ESF offers in-service, non-intrusive diagnostics, testing, and performance measurement.

Both DS1 and T1 transmission utilize a transmission rate of 1.544 Mb/s. Consequently, the terms DS1 and T1 are often used interchangeably by non-engineering telecommunications practitioners. However, there is an engineering distinction between the two. “DS1” connotes an all digital transmission stream and is especially appropriate terminology in the optical equipment environment. “T1” connotes a particular type of carrier transmission system that operates only over twisted-pair copper cable.

Table 1 shows different transmission rates for T-carrier facilities according to this standard. T1 and T3 facilities are most commonly used. Each T1 link offers a digital 1.536 Mbps transmission capacity and 8 kbps of overhead added for framing information.

Digital Facilities	**Transmission Rates**	**Number of T1 Equivalents**
T1	1.544 Mbps	1
T1C	3.152 Mbps	2
T2	6.312 Mbps	4
T3	44.746 Mbps	28

Table 1. T-Carrier Transmission Hierarchy

A.7. SONET

Approximately 10 years ago transmission specialists recognized that there were drawbacks to the existing digital and optical standards and systems. A group of these specialists, representing many manufacturers and institutions, formed a committee to develop a standard to address and correct these drawbacks. In 1988, four years of standards work culminated in the publication of a worldwide standard for optical communication. This standard is known as Synchronous Optical Network or "SONET" in the United States, and "Synchronous Digital Hierarchy" (SDH) elsewhere. This standard has subsequently been subdivided into various elements that are intended to address a number of network functions. Most of the standard subset elements are fully developed while some development work remains to be completed on the systems management component.

SONET standards development was defined in phases. Phase I, completed in 1987, included the rates and format definition as well as the optical interfaces. Phase II, completed in 1991, included definition of the electrical interface and the protocols for data communication channel protocol suites. Phase III, which is yet to be fully approved, defines the message sets to be used over the data communication channels to carry out specific operations, administration, maintenance and planning (OAM&P) functions. However, it should not be deduced that this standard in and of itself will make all SONET equipment completely interchangeable or even fully compatible. Currently, each equipment manufacturer still has some features and capabilities that are unique to their system.

Hence, once an organization undertakes the development of a network with a particular manufacturer's equipment, it is highly likely that in the interest of overall operational consistency, the organization will be compelled to carry through any system expansions with that manufacturer's equipment. This issue should be of particular interest to WSDOT because the Northwest Region SONET system that is currently under construction is utilizing equipment manufactured by Alcatel. Alcatel is a reputable French firm with manufacturing facilities in the U.S. Dominant player in the communications equipment market in the U.S. are Northern Telecom (a Canadian firm) and AT&T.

SONET standards provide for a digital architecture wherein an individual DS1 bitstream is clocked synchronously, making it possible to access individual DS1 channels without the expense of double multiplexing and demultiplexing at each access point.

SONET defines a hierarchy of rates and formats to be used by vendors, carriers, and end-users for optical transmission at and above the 51.840 Mb/s rate for Optical Carrier Level One (OC-1). It should be noted that the electrical equivalent of an OC-1 signal is known as a Synchronous Transport Signal-Level 1 (STS-1{ 51.840 Mb/s}) and is the highest electrical signal rate in the synchronous digital hierarchy.

The 51.840 Mb/s rate is derived from a DS3 signal (44.736 Mb/s rate) plus overhead control and maintenance channels. Consequently, in the SONET realm, OC-1 is an acronym for the ability to carry the equivalent of one DS3 channel (≈45 Mb/s). Hence, an OC-3 SONET system can transport three (3) DS3 signals, an OC-12 twelve DS3 signals, and so forth.

The SONET hierarchy currently addresses transmission up to 2.5 Gb/s (OC-48) and can be extended, once equipment is available, to more than 13 Gb/s. It is also worth noting that a bit rate of 2.488 Gb/s (2.488 billion bits per second) is equivalent to over 32,000 voice or data channels or 1,344 video channels (using a DS1 compression rate). Consequently, optical transmission systems are the economic choice for transporting large cross sections of traffic.

SONET grows in multiples of the basic signal into the multi-gigabit range. A SONET architecture has the ability to add/drop signals on a per channel basis. Table 2 shows examples of different transmission rates.

SONET Levels	Transmission Rate	DS1 Equivalent	DS3 Equivalent
OC-1	51.840 Mbps	28	1
OC-3	155.520 Mbps	84	3
OC-12	622.080 Mbps	336	12
OC-48	2488.320 Mbps	1344	48

Table 2. Transmission Rates for SONET Networks

The basic signal can be divided into a portion that is assigned for transport overhead and a portion that contains the payload. The overhead bits can be used for many purposes, such as maintenance, user channels, frequency justification, channel identification, and growth channels. In addition, the payload envelope contains path overhead whose functions include a path trace that ensures receiver to transmitter terminal connection, a path error monitoring function, and other similar control functions.

It is worth noting that a rapidly emerging communications technology that leverages the SONET transmission capability is asynchronous transfer mode (ATM) which uses a transmission rate of 155.520 Mbps. When SONET is used as the long haul transmission for this technology the designation for the transmission rate is OC-3c which denotes that the transmission is not subdivided into discrete, fixed bandwidth, channels because ATM provides a flexible bandwidth capability based upon demand.

A.7.1. SONET Network Equipment

SONET network elements are pieces of equipment that must be embedded in the network to make the SONET concept a reality. SONET network element functions can be divided into two groups:

1. Multiplexing several STS-1 electrical signals into an STS-N signal, and performing the electrical-to-optical conversion;
2. Conversion of network signals into STS-1 payloads.

Currently, equipment manufacturers requirements have been defined by Bellcore for five SONET network equipment elements. These are:

- Add/drop multiplexers (ADM)
- Digital access and crossconnect system (DCS)
- Switch interface
- Signal regenerator, and
- Digital loop carrier (DLC) system with SONET interface

It should be noted that an ADM operating in the terminal mode becomes a SONET multiplexer.

A.7.1.1. Fiber Transmission System

These types of network elements multiplex a number (N) of STS-1 signals to form an STS-N that is then converted to an OC-N optical signal. This network element can accept DS3 terminations in addition to the STS-1 signal interface.

A.7.1.2. Terminal Multiplexers

The terminal multiplexer (TM) network elements terminate several DS1 signals and assemble them into STS-1 payloads. One type of terminal can terminate up to 28 DS1 signals and functionally replaces the M13 multiplexers in use today. These types of network elements are equipped with an integrated electrical-to-optical converter providing an OC-1 optical signal. Another type of terminal can terminate up to 84 DS1 signals and include a byte interleave function that produces an OC-3 interface.

A.7.1.3 Add/Drop Multiplexer

Add-drop multiplexer (ADM) network elements are placed in series along a SONET route and allow DS1 signals to be added to or dropped from an STS-1 signal. The ADM has an "east" and a "west" directionality, and DS1 terminations can be "to" or "from" either direction. One type of ADM provides add-drop access to one STS-1. It can be equipped with integrated optical converters for OC-1 compatibility. Another type of ADM may allow add-drop access to multiple STS-1 signals and be equipped with integrated multiplexers and optical converters. Add-drop multiplexers can also be equipped with time slot interchangers to allow digital cross-connect functions among the DS0 channels carried in the STS-1 payload.

A.7.1.4. Access Multiplexers

Access multiplexer (AM) network elements make use of the inherent byte visibility of the SONET format to terminate DS0-based services directly to an STS-1 payload. This is accomplished without the need to first multiplex them into DS1 signals and then into DS3 signals as is done today. AMs typically integrate the functions of a terminal multiplexer (TM) or ADM with the line circuit termination equipment of a digital loop carrier. One type of AM may terminate 672 DS0 channel equivalents on one STS-1 and may be equipped with integrated digital cross-connect functions.

A.7.2. SONET Microwave Equipment

SONET microwave radio relay equipment is currently available from at least one and possibly three different manufacturers. This equipment offers an OC-1 level transmission support and can support the SONET OAM&P control suite. It is capable of interfacing to other standard SONET equipment.

A.8. Channel Banks

The channel bank is one of the better known types of termination-multiplexing equipment in telephone plant. A digital channel bank digitizes analog voice and data signals, and multiplexes these channels into a greater hierarchical level. At the remote end, the opposite process is undertaken, demultiplexing the hierarchical level into individual channels.

The distinction between channel banks and digital loop carrier systems is that channel banks apply to the trunk side between the TSMC and a communications node, while digital loop carriers applies to the field terminal equipment side to the distribution plant, in particular.

Channel banks and carrier systems can also be analog, supporting the older FDM hierarchy. Analog-type channel banks have reached a "mature" stage in their deployment.

Digital channel banks have two basic functions. They convert analog voice to digital code, and vice versa. They combine or multiplex the resulting digital streams from several active sessions (voice or data) onto a single stream. Time division multiplexing (TDM) with byte interleaving is the norm. To achieve these tasks, digital channel banks have equipment to provide proper voice frequency (VF) and signalization interfaces with the TSMC. In addition, they provide filters to limit the transmitter input frequency (300-3400 Hz), so that pulse code modulation (PCM) techniques employing 8000 samples per second suffice for faithful signal reproduction, and provide the means for controlling the timing and synchronization. The data communication practitioner may view channel banks as specialized T1 multiplexers.

Channel banks generally consist of a common-equipment section (functions that are identical across all channels), and individual channel unit cards that interface to the specific type of voice or data trunk in question (two-wire, four-wire, tie-line, et cetera). These channel units are characteristic to a particular channel, and their basic function is to provide the interface between the TSMC trunk apparatus and the circuit terminating on the channel bank. The correct type of line card for the channel bank ensures proper transmission and network signaling functions for a particular circuit.

A.9. DIGITAL CROSSCONNECT SYSTEMS

Digital crossconnect systems are the interconnection points for terminals, multiplexers, and transmission facilities. They are equipment frames where cabling between the system components is crossconnected to provide flexibility for restoration, automated rearrangements, and circuit order work. Once implemented with jack fields, this function is now usually implemented electronically with a piece of equipment known as a "DCS." These DCSs, initially used by telephone companies, are now being acquired by end-users to facilitate private network rearrangement.

A DCS is a computerized facility that allows DS1 lines to be remapped electronically at the DS0 level; DCSs remapping DS3 signals at the DS1 level are also available. DCSs allow the assignment and redistribution of 64 kb/s channels among various DS1/ T1 systems connected to the DCSs at the digital level.

DCSs also provide per channel DS0 test access in digital form. DCS is not a direct replacement for, nor an alternative to, any single network component. It is, however, a versatile piece of equipment that has several roles in a large tele-communications network. The first DCS was AT&T's Digital Access and Cross-connect System (DACS), and this is why this type of equipment is occasionally known by the "DACS "acronym. Currently, there are over two dozen manufacturers of DCSs.

The terms "slow switch," "nailed-up switch," and "channel switch" are also occasionally used, the last one especially in an ISDN context. A DCS is functionally a rudimentary switch minus automatic path setup protocols and switching logic. In SONET there are two related types of equipment: the broadband DCS and the ADM. The distinction is as follows:

- A DCS needs an initial command to affect the connection; otherwise bits are not mapped across the equipment.

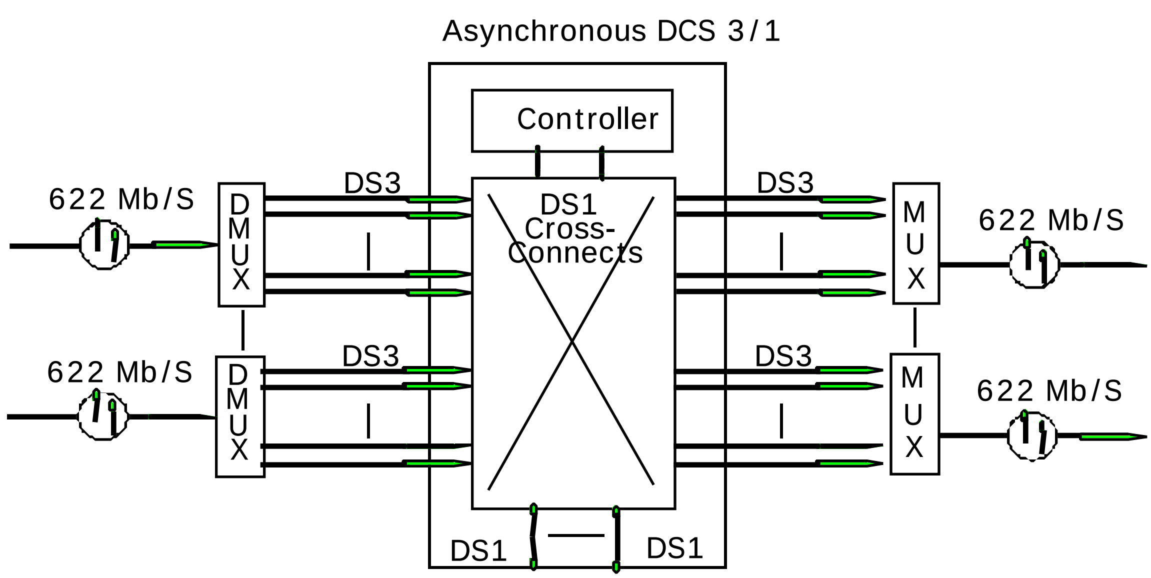
- An ADM will pass through all signals until a command is given to it to mask a specified portion of the bandwidth.

A.9.1. DCS Applications

A DCS serves as a node in digital distribution networks. Several key applications exist for DCSs including segregation, concentration, on-route circuit combination, elimination of back-to-back channel banks, improvement of plant utilization, elimination of nailed-up connections, testing, and transmission facilities.

Large private networks may benefit from DCS technology because it is ideally suited to large telecommunication applications. DCSs allow signals to be routed without having to be demultiplexed. Typical applications include:

- Remote diagnostics, maintenance, and provisioning;
- Routing and restoral;
- Network reconfiguration and bandwidth allocation; and
- Circuit "grooming" and concentration.



Asynchronous DCS 3/1 functional diagram.

DCSs allow networks to be reconfigured from a centralized network management center without physical rewiring or changes. Additionally, these changes can be carried out in a matter of minutes or even seconds. The equipment allows rapid and inexpensive cross-connection of DS1 channels; the connections can be easily monitored, tested, disconnected, and reconfigured from local or remote terminals. A DCS serves the same function in the digital environment that a distributing frame serves in an analog environment.

A DCS in a private network performs all the functions performed by a DCS in a telephone company application. A user may be interested in mapping out a particular DS0 channel for testing purposes, without having to demultiplex the entire DS1, down to the VF level using a channel bank. This reduces the equipment and labor costs associated with testing.

A naming convention is employed to describe DCSs. The x/y nomenclature is to be read as follows: x is the rate of the carrier facilities the DCS terminates in the DSx hierarchy; y is the channel rate upon which the crossconnect function is performed, again in the DSx terminology. A 1/0 DCS terminates DS1 channels (1.544 Mbps) and cross-connects DS0 (64-kbps) channels. A 3/1 DCS terminates DS3 channels (44.736 Mbps) and cross-connects DS1 channels.

Wideband DCSs (WDCS) support 3/1 or 3/1/0 functions and Broadband DCSs (BDCS) support 3/3 functions. Sophisticated systems can support unlimited broadcasting where "n" output ports are connected to one incoming port; this supports digital bridging applications. Currently, 3/3 DCSs support asynchronous DS3, and recently installed DCSs are field-upgradable to SONET STS-1 systems.

Several key technical applications exist for DCSs in a private network. These are segregation, concentration, on-route circuit combination, elimination of back-to-back channel banks, improvement of plant utilization, elimination of nailed-up connections, testing, and sparing. Some of these applications are defined below.

A.9.1.1. Concentration

This refers to the elimination of unfilled DS0 slots from incoming DS1 lines, and repackaging the active slots (assuming that they are all meant for the same remote destination) onto fewer DS1 channels.

For example, if two DS1 trunks are such that the first uses 10 out of 24 slots and the second uses 11 out of 24 slots, then instead of extending two DS1s remotely, a DCS can be used to remap these slots into a single DS1 outgoing link. This capability will likely reduce the requirement for having to provide a channel bank at the TSMC for every communication node in the network. In a network, incoming DS1 lines from field terminal systems may be only partially filled. Several DS1 lines in this category can be remapped with a DCS onto fewer but filled DS1 lines. Channels with common destinations can be packed so as to increase the fill of the T1 lines and of the terminal equipment.

A.9.1.2. Reduction of Channel Banks

Elimination of back-to-back channel banks is really what a DCS is all about. It allows information channels to be redirected without having to be demultiplexed and translated to an analog format for a manual copper wire connection at the frame level or patch panel. This saves the cost of the channel banks, saves physical floor space, and retains more signal integrity.

A.9.1.3. Transmission Facilities and Other Facilities Sparing

Envision two TSMCs connected with 1-for-n or m-for-n sparing: the DCS allows a failed carrier system to be replaced with a backup link in an expedited fashion. DCS rerouting time is now as short as 50 ms. A DCS crossconnect map is defined by non-real-time external commands entered from an administrative terminal and stored in a system database. Circuit reconfiguration is controlled from a local or remote terminal. Service technicians do not need to manually change a circuit, permanently or with jumpers, or to patch in for diagnostic purposes. The desired circuit can be "located" without having to employ a channel bank to bring the DS1 down to a VF mode. The duration of a crossconnection implemented through a DCS can vary from hours to years. The newer and larger DCSs include SONET interfaces and can support SONET self-healing rings.

A.10. SUPPORT STRUCTURE CONSIDERATIONS

Support structures are defined as those outside plant components of the communications system that are required to facilitate installation and maintenance of the field portion of the traffic management system. Support structure requirements are derived from the physical topology that is employed to develop the communications system. The fundamental design requirement for support structures is to mechanically accommodate the field portion of the communications network while providing some recognition for maintenance and growth. Support structures typically require a significantly large proportion of the capital investment in a communications system. As such, they should be designed to satisfy the requirements of long-term system goals.

Support structures will normally consist primarily of conduits, cable vaults (manholes), pull boxes, equipment cabinets, and controlled environmental vaults (CEVs). These structural facilities are the means by which the communications cables are routed for connection to field devices. Depending upon a specific design, CEVs may or may not be utilized as a housing for communications node transmission equipment.

A.10.1. Conduit Parameters

The conduit system portion of the support structures requires significant planning effort. Aside from the logistics associated with installing conduits along a roadway, the limitations imposed by cable installation introduce additional design constraints. Conduit systems must be designed to minimize the tensile pull load applied to both the copper and optical fiber cables during installation. Both the copper and optical fiber cable tensile threshold should be considered in all aspects of support structure planning. Thus, the conduit design should result from an analysis of the copper and optical fiber cable installation methods.

Contrary to popular thinking, the design limitation parameter when developing a conduit system design is not the pull tension strength of the optical fiber cable, but rather, it is the copper cable. Optical fiber cable designed for use in an outside plant environment, in general, can withstand a pull tension of 600 pounds. Whereas, in general, a twisted-pair copper cable designed for an outside plant environment can withstand a pull tension equal to approximately 10 pounds per pair. Hence, in the instance of a 25 pair cable this equals a maximum pull tension of 250 pounds.

Since installation pull tension is caused primarily by friction, and friction is a function of the cable rubbing against the conduit, minimizing contact points is key to conduit design. A primary design element is to reduce the abrasive characteristics caused by both conduit bends and the conduit itself. A straight conduit system provides the following benefits:

- Facilitates cable installation by allowing greater manhole spacing while remaining within the bounds of cable tensile pulling limitations.
- By reducing the resistive elements of conduit topology, longer cable sections can be installed.
- Provision of longer cable sections reduce optical splices and system performance is enhanced by limiting attenuation due to splicing.
- With simplified cable pulling and minimal optical splicing, installation costs are reduced.

Pull boxes are typically required when radical changes in direction are necessary due to a limited space to accommodate larger radii bends. Where possible, horizontal conduit bends should be designed with a minimum 30-foot radius, and vertical conduit bends should be designed with a minimum 4 foot radius. Where conditions preclude the use of these types of bends, pull boxes or vaults should be used to provide access to the cable during installation.

To provide for the installation of multiple cables in a conduit system, it is strongly recommended that any initial system design provide for at least two spare ducts beyond the initial duct requirements. Minimum duct size should be not less than 1.12 inches in diameter.

A.10.2 Cable Vault and Pull Box Parameters

Cable vaults are defined as underground concrete structures employed as an interface point for distribution conduit connections to the mainline conduits, and to house stored cable and splices. Cable vaults may also be used as access points to facilitate cable pulling.

In communication conduit system applications, pull boxes are utilized to access the conduit system to facilitate cable pulling when the conduit geometry is not conducive to a single cable pull. Pull boxes may also be utilized on or adjacent to above ground structures where it is not possible to install a cable vault or large radii conduit bends.

Once the optimal conduit design geometry is resolved, the logistics associated with cable pulling will determine the location of cable vaults and pull boxes. That is, the minimum quantity of cable vaults/pull boxes is a function of the allowable cable pull sections. The quantity of cable pull sections will be based either upon the tensile limitations of the cables to be installed or the requirement for a splice point. Since the copper twisted-pair cable usually has the lowest tensile pull limit, it provides the most conservative model when considering allowable cable pull sections.

As a rule of thumb, if copper cable is included in a mainline system, pull box or vault spacing can be established at approximately 500 to 1000 foot intervals, assuming there are no unusual bends or a large number of bends. If only optical fiber cable is included in a mainline system, pull box or vault spacing can be established at approximately 1000 to 1500 foot intervals, assuming there are no unusual bends or a large number of bends. The specific cable pulling limits for a discrete design can be determined through theoretical tension calculations. Using the theoretical cable installation limits, the conduit geometry and exact cable vault/pull box locations should be refined to reflect specific field conditions.

A.10.3. Controlled Environment Vault

The sophisticated optical and electronic communication equipment at a communications node may require a controlled environment. It is typical to install this type of equipment in shelters that provide a building type of environment. While above ground equipment shelter buildings have been commonly used in the communications industry, there has been an increasing trend toward the use of underground vaults for housing this equipment. A controlled environment vault (CEV) provides security and aesthetic advantages over an above ground building. A CEV provides excellent protection for costly equipment in a roadway environment because most of the shelter is buried and therefore not susceptible to damage by wayward vehicles or vandals.

A CEV is constructed of concrete or steel and is buried in the ground, with only an entrance hatch and air vent protruding above the finished grade. It is equipped with cooling and heating systems to maintain a controlled temperature and humidity environment for the installed optical and electronic equipment. It is also equipped with gas detectors and alarms for personnel safety and an automatic sump pump to protect against flooding. Both concrete and steel CEVs have similar characteristics with respect to electronic equipment accommodation. We wish to note that steel CEVs are somewhat more desirable as an enclosure because they better lend themselves to heat dissipation in the event of a power outage.

A.11. COMMUNICATION HUB PARAMETERS

Communications hubs will contain the equipment required for a video transmission system, video distribution system, voice and data transmission systems, voice and data distribution systems, and associated optical fiber and twisted-pair cable termination hardware. The equipment required in each communications hub should be installed inside a shelter that provides a suitable controlled environment for the reliable operation of the system. The design of communications hubs can be relatively standardized such that many of the network elements will be the same from node to node, but types and quantities of communication equipment at each hub will vary depending on the types and quantities of field devices served by a particular communications hub.

A communications hub will aggregate the individual data and video channels from multiple device locations and consolidate them into a multiplex channel transmission to the traffic operations center. Through the use of time slot interchange, a form of virtual switching may be effectuated with this design arrangement.

The mainline transmission equipment at a communications hub will include SONET voice and data transmission system equipment as well as the video transmission system equipment for multiple device locations. The equipment will connect to the optical fiber cabling via a fiber termination panel as well as to copper twisted-pair cable through a terminal block. Due to the varying quantities of required circuits, the transmission equipment configuration at any two hubs will not be exactly the same.

A.11.1. Distribution Node Parameters

Communication distribution nodes should contain sufficient equipment to support one video channel and three data channels. This would include any associated optical fiber and twisted-pair cable and termination hardware. The equipment required in each distribution node can be installed inside a standard traffic control cabinet that provides a suitable environment for the reliable operation of the system. The design of distribution communication nodes can be relatively standardized such that virtually all of the network elements will be the same from node to node. Most notably a distribution communications node design will not likely require a controlled environment vault.

In general, a distribution node will aggregate the individual data channels and video channel from each device location, consolidate them, and into a single channel transmission to the traffic operations center. It should be noted that the distribution node design is a point-to-point design. There is no switching capability associated with this method.

The transmission equipment at a communications distribution node will not include SONET transmission system equipment and will be limited to only include video transmission support for one camera site, one Type 170 controller, and one camera pan, tilt, zoom (PTZ) control. The transmission equipment will connect directly to a single mode fiber via a fiber termination.

A.12. FUTURE TRENDS

A.12.1. Broadband Cable Based Technology - ATM

ATM (Asynchronous Transfer Mode) refers to a switching technique for broadband signals. It is often labeled as a standard for cell relay or fast packet technology. In the purest sense, ATM switching reduces the processing of protocols and utilizes statistical multiplexing. ATM is primarily a connection-oriented technique that can transport both connection and connectionless services at both a constant bit rate and variable bit rate. ATM is the closest approximation to a true "bandwidth-on-demand" capability that has been developed to date. ATM is an asynchronous technology because the cells transmitted by the user are not necessarily periodic.

ATM switching also provides the capability to standardize on one network architecture and platform, where ATM provides the switching platform and SONET provides the digital infrastructure and physical transport. Thus, the entire network operates on one switching and multiplexing principle for transmission of multimedia services. ATM is closely associated with broadband integrated services digital networking (B-ISDN) in that it is designed to provide the transfer mode for B-ISDN services. ATM can trace its roots to a standards based development.

The two major physical interface types available to ATM are SONET based and cell-based interfaces. When ATM uses a SONET based interface, the combined transmission of multiplexed cells is inserted into the virtual channel and network monitoring and management functions are handled outside the virtual channel. These channels correspond to the SONET path, line, and section levels. A very important point regarding ATM however is that the ATM user-to-network interface access rate is fixed at a signal rate of either 155.52 Mb/s (SONET OC-3c) or a rate of 622.08 Mb/s (SONET OC-12). Thus, ATM can be integrated with the synchronous digital hierarchy (SDH).

The transmission characteristics of ATM and SONET signals are different. SONET is unaware as to what goes on beyond a single physical link and so does not take an end-to-end routing view since it is a physical layer standard (Layer 1 of the OSI reference model). Additionally, SONET is a synchronous standard in the sense that the position of the information within the frame determines who owns that information. ATM is asynchronous in the sense that the position of the information does not establish ownership; a header field is added to each block of information to identify who owns the data in the block. The routing capability of ATM can be interpreted as a network layer capability or a link layer capability. Most network developers seem to support a data link layer interpretation of the ATM functions. This interpretation implies that ATM can use SONET at the lower layer as a physical conduit.

SONET is an excellent transmission mechanism for not only carrying large user traffic cross sections, it also provides ample network support in the areas of operations, administration, and maintenance, but all information must be carried at one of the standard synchronous digital hierarchy (SDH) transmission rates. SONET does not directly accommodate variability in bandwidth. Based upon network traffic requirements, ATM can allow an organization of the SONET payload so that varying bandwidth signals can be effectively carried.

Nevertheless, this attribute of ATM is only important when the network has a need to support temporary connection traffic (i.e., connections that are put up and taken down in a relatively short period of time) or to support “bursty” type traffic (i.e., traffic of high bandwidth, short duration). We do not view this need as being the case in ITS traffic management network design. Virtually all of the network connections and transmission in an ITS traffic management network are permanent connections using dedicated transmission. To this end, from a Regional perspective, SONET multiplexers are more appropriate to the communication application than the use of a switch system.

Another significant network design issue is the support of a “fail safe” network backbone. Utilizing SONET multiplexers and appropriate infrastructure construction, it is quite simple to create a “ring” topology for the backbone network. This topology minimizes the requirements for optical fiber and optical line interface units and thereby reduces cost. To approximate a comparable level of reliability using switching technology would necessitate the development of a “mesh” topology which would at least double, and perhaps triple, the requirements for optical fiber medium and optical line interface units.

From a practical application perspective, ATM may be an appropriate technology to utilize for interRegion transmission network requirements, but, currently, there appears to be minimal use for it from a transportation systems perspective. In a broader view, however, it would likely be an appropriate technology to utilize in the support of administrative communications applications. Especially in support of network services whereby wide area networks (WANs) are required to support high throughput bursts for multimedia and video transmission.

A.12.1.1. ATM Standards

In 1988, International Telephone and Telegraph Consultative Committee (CCITT) Recommendations I.113 and I.121 defined the first two standards for B-ISDN. These recommendations were revised in May of 1990. At the same time, eleven more draft recommendations: (I.150, I.211, I.311, I.321, I.327, I.361, I.362, I.363, I.413, I.432, and I.610) were published detailing the functions, service aspects, protocol layer functions, OAM&P, and user-to-network and network-to-network interfaces. Each standard was defined as a B-ISDN standard to operate over the ATM architecture. Most of these draft B-ISDN standards can be found in the CCITT 1992 White Books. Suffice it to say that the ATM protocol functions correspond roughly to the first two layers of the Open System Interconnection (OSI) reference model. The ATM protocol stack is comprised of both the Physical and ATM layers. The physical layer is either SONET based or cell based. The ATM layer is comprised of the virtual channel and virtual path sublayers.

ATM “standards” are being developed in the U.S. by a group known as the “ATM Forum.” This is not a recognized standards body but rather an amalgamation of manufacturers and interested users which tacitly are developing a defacto standard, not a sanctioned standard. Currently there are few if any fully agreed to “standards”. Most of the standardized elements of ATM are predicated upon the standards efforts of the CCITT in the development of Broadband ISDN. More importantly, specifications for ATM are still in a high state of flux and virtually all systems at this time are proprietary. Conversely, SONET is a highly standardized system whose standards have been developed under the auspices of the American National Standards Institute which is the U.S. representative to the CCITT. Only the operations and maintenance software elements remain to be fully standardized. It is expected that this standard should be approved sometime in 1995.

A.12.2. Wireless Services

Wireless technology will likely be the most volatile of the transmission technologies for the foreseeable future. The telecommunications industry is anticipating an explosion of technology and services in this field. This will range from introduction of "personal communications services" (PCS) to substitution of wireless technology for transmission that has been historically cable based.

In the transportation industry, an example of this is the introduction in Los Angeles of spread spectrum radio transceivers to support the communication requirements of traffic control for 135 intersections.

PCS is a microcell based radio technology which will likely have a number of applications in ITS services. An example, would be the real time accessing of a ride sharing database to support commuter requirements.

A.12.2.1. Advanced Traveler Information Systems

ATIS information can be displayed on various devices such as a Seiko watch or a Personal Digital Assistant (PDA), such as Tandy's Z-PDA, Apple's Newton and the Envoy from Motorola. The wireless ATIS services to be offered will likely fall into one of two categories. These will be either a broadcast communication type service or an interactive, two-way communication type service. It should be noted that the mountainous topology of the subject service area will substantially influence the wireless technology selected to provide the desired ATIS service.

In selecting the type of service to be provided and the transmission method to be utilized, consideration must be given to the character of the information to be provided (or obtained) and the need to confirm that it was actually received. Data transmission between a management center and in-vehicle devices can be satisfied by a range of wireless options, including:

- State owned trunked radio system
- Dedicated radio system
- Commercial cellular digital services
- Radio Data System using the subcarrier available on commercial FM radio systems

The determination of an appropriate wireless technology will be made from the application requirement.

A.12.2.2. Frequency Spectrum Issues

WSDOT ITS planners and other staff should be aware that the anticipated applications of wireless technology in the ITS realm may be constrained by regulatory requirements.

The forecasted explosion in wireless communications depends not only upon consumer acceptance in the marketplace, but also the ability of the radio frequencies required to operate efficiently. As more and more technologies are developed, the fighting among these new technologies for access to the nation's limited radio spectrum is becoming more fierce.

An ITS network of the future is envisioned as linking various existing and emerging technologies to create an integrated system of computers, wireless radio communications systems, and various sophisticated sensors to be used in automobiles and highways which will alter the way Americans drive and interact with the roadway.

ITS will have an open architecture, nationally compatible system (allow in components from many different sources and vendors to be combined in various configurations) that will accommodate a wide variety of newly developing traffic safety and management technologies, including advanced surveillance, sensor, communications, software, data management, and display technologies. The federal government will provide leadership and assist in the development of national standards, and fund certain research.

USDOT has obtained spectrum for ITS through the FHWA. It requested NTIA and the FCC to set aside frequencies for ITS in the new 220-222 MHz land mobile band. Five nationwide, narrow band frequency pairs in this band were subsequently allotted to FHWA by NTIA for experimental ITS use for a 15-year period, with an option to renew. ITS has been registered as a priority national system (providing interference protection). FHWA will maintain administrative control over the use of these frequencies, and intends to share their use with its partners in selected ITS projects. FHWA has divided the frequencies into base station and mobile frequencies, and imposed attenuation and power limits. Assignments will be made for a period of one to three years, with possible extensions based on technical merit. Radio equipment that is to be operated on these frequencies must be type accepted by the FCC. The maximum possible effective radiated power (ERP) from a mobile station is 50 watts; ERP limits for base stations range from 5 to 500 watts, depending on the antenna height. Mobile stations must maintain their carrier frequency within 0.000015 percent; base stations within 0.00001 percent. Use of these frequencies shall otherwise conform to Part 90 of the FCC's rules governing private land mobile radio services. The final digital modulation type (or types) that will be authorized on these frequencies has not been determined.

The deployment of operational ITS systems will likely use frequencies in the same band, drawn from the non-government, nationwide, non-commercial allotment managed by the FCC.

There are a number of applications that appear to require spectrum above 2 GHz. Among these are "adaptive" cruise control (i.e. adjusting a car's speed based on the proximity of other cars or hazards), centrally determined route guidance systems (using microwave or infrared beacons), and automatic vehicle identification (AVI). AVI will need spectrum initially at 2.4 GHz and eventually in the 5.8 GHz band in order to be compatible with European systems.

It is doubtful, however, that enough dedicated spectrum will be made available to support an entire ITS infrastructure. FHWA and ITS America have been actively working to identify current and planned communications technologies that may have sufficient merit to be used for ITS, such as the emerging technologies of low-earth orbit satellites (LEOS) and personal communications services (PCS), but also the frequency spectrum bands that may be utilized to support ITS technologies. It may well be that ITS could also represent a new market for cellular service providers. This identification effort by FHWA and ITS America has been refined to the extent that determinations are being made as to what spectrum bands it is felt that ITS service should be the prime service in a particular spectrum band and in what areas can be spectrum be effectively shared with other radio services.

An example of ITS's ability to share spectrum with an existing technology is FHWA's FM Broadcast Subsidiary Communications Authorization experiment, aimed at developing a high speed, low-cost broadcast data link on existing FM "subcarrier" channels to distribute traffic and other information over conventional car radios. However, spectrum sharing will not likely be practical for ITS core emergency and control services that need dedicated systems and spectrum, such as distress signaling, collision avoidance, and vehicle guidance systems.

Though the FCC has yet to initiate a single, unified docket for ITS, it has proposed permanent rules for the existing Automatic Vehicle Monitoring (AVM) system (used to locate and track vehicles using non voice methods and to relay information to and from vehicles), which will be an important component of ITS. The FCC has proposed continuing to use frequencies in the 902-928 MHz industrial, scientific, and marine [ISM] band for AVM, as well as in the bands below 512 MHz on a restricted basis. There are currently seven federal government and non-federal radio functions authorized in this band, and each service must not cause interference to and must accept interference from all services higher in the hierarchy.

It should be noted that portions of the 902-928 MHz ISM band are also popular for wireless systems used in conjunction with ITS electronic toll and traffic management (ETTM) system and traffic control system applications.

Interference from higher ranked ISM devices and government radar systems has not yet been a problem. However, as the number of ITS systems increase the possibility of receiving interference will also increase. Similarly, the potential for interference increases as the number of ISM devices multiply. For example, hospitals are now using wireless local area networks to relay patient data directly from a hospital bedside to remote computers, enabling more effective, real-time responses to medical emergencies. Interference to ITS systems might also be received from unlicensed devices (such as cordless telephones, spread spectrum systems, wireless security alarms, wireless meter reading systems, wireless stereo/video devices, and wireless barcode readers) authorized under Part 15 of the FCC's rules, and amateur radio operations under Part 97. Although ITS systems would be entitled to interference protection from unlicensed devices, it can be time-consuming to identify the source of the interference and eliminate the problem.

The FCC has proposed that all AVM equipment be preapproved by the Commission through the relatively burdensome "type acceptance" procedures of Part 15. Because of the significant potential for interference as such systems become more widespread, it will be increasingly important that new equipment complies with required technical standards. This may also be an indicator regarding FCC action on other ITS equipment.

One of the central dilemmas facing ITS developers is the availability of not only adequate frequency spectrum, but spectrum where ITS service has the prime priority. Currently, this only exists between 220 and 222 Mhz.

As the ITS concept continues to grow and additional technologies are developed, the FCC will no doubt conduct future rule makings to resolve spectrum allocation and interference issues. However, because ITS will be competing with other emerging technologies for scarce radio spectrum, such rule makings will be very contentious. The FCC's central role in the development of many ITS services should not be overlooked.

GLOSSARY

asynchronous—Transmission in which each information character is individually synchronized, usually by means of start and stop elements. Also called start-stop transmission.

ATM (Asynchronous Transfer Mode)—A connection-type transmission mode carrying information organized into locks (header plus information field); it is asynchronous in the sense that recurrence of blocks depends on the required or instantaneous bit rate. Statistical and deterministic values have been proposed that correspond respectively to the packet and circuit values defined for information transfer mode.

bandwidth—The width of a communication channel measured as frequency (in cycles per second, or hertz). A channel's bandwidth is a major factor in determining how much information it can carry.

broadcast—The act of sending a signal from one station on a LAN to all other stations, all of which are capable of receiving that signal.

channel—1) A path for electrical transmission. Also called a circuit facility, line, link or path. 2) A specific and discrete bandwidth allocation in the radio frequency spectrum (for example, in a broadband LAN) utilized to transmit one information signal at a time.

DS-1 (Digital Service, level 1)—The basic 24-channel 1.544 Mbps pulse code modulation system used in North America (2.048 Mbps elsewhere). At this service level you can transmit 24 voice conversations, each encoded at 64,000 bits per second. 1.544 Mbps is the old Bell System standard and 2.048 is the CCITT standard.

DS-2 (Digital Service, level 2)—It is 6.312 Mbps in North America

DS-3 (Digital Service, level 3)—Term referring to the signaling rate of a T3 network--44.736 Mbps.

EMI (Electromagnetic Interference)—External signals that disrupt the data being transmitted on the local area network or electronic device being operated. Typically, these external signals emanate from universal motors with brushes, fluorescent lights, personal computers, printers or other devices including copy machines, etc. The Federal Communications Commission (FCC) regulates this emission area.

optical fiber technology—Transmission of energy by light through glass fibers. A technology that uses light as information carrier. Fiber optic cables (light guides) are a direct replacement for coaxial cable and wire pairs.

optical fiber cable—A very thin, flexible glass or plastic fiber carrying high-bandwidth digital or analog signals in the form of pulses of light. Fiber can carry a thousand times more information than conventional copper wire; the fibers are immune to electrical interference. Lasers or light-emitting diodes (LEDs) emit pulses of light, which are propagated through the fiber by a process of internal reflection. A fiber consists of two layers of glass or plastic enclosed in a protective buffer.

protocol—A set of procedures for establishing and controlling communications.

ring—A network topology in which stations are connected to one another in a closed logical circle. Typically, access to the media passes sequentially from one station to the next by means of polling from a master station, or by passing an access token from one station to another.

SONET (Synchronous Optical NETwork)—An emerging broadband fiber network formed by a family of network elements that conform to the SONET interface requirements. SONET is a transport network of synchronously multiplexed tributary signals. SONET protocols define a hierarchy of transmission rates, the basic signal rate being 51.840 Mbps. SONET grows in multiples of the basic signal into the multi-gigabit range. Examples of different transmission rates are as follows:

- **OC-1**— Data Transmission rate of 51.840 Mbps.

- **OC-3**— Data Transmission rate of 155.520 Mbps.
- **OC-12**—Data Transmission rate of 622.080 Mbps.
- **OC-48**—Data Transmission rate of 2488.320 Mbps.

star—A network topology consisting of one central node with point-to-point links to several other nodes. Control of the network is usually located in the central node or switch, with all routing of network message traffic performed by the central node.

synchronous transmission—Transmission in which there is a constant time between successive bits, characters, or events. The timing is achieved by sharing of clocking.

topology—1) physical topology—The configuration of network nodes and links. Description of the physical geometric arrangement of the links and nodes that make up a network, as determined by their physical connections. 2) logical topology—Description of the possible logical connections between network nodes, indicating which pairs of nodes are able to communicate, whether or not they have a direct physical connection. Examples of network topologies are as follows:

- Bus
- Ring
- Star
- Tree